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COMPOSITION AND CONCENTRATIVE PROPERTIES OF HUMAN URINE

by David F. Putnam

Prepared by

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COMPOSITION AND CONCENTRATIVE PROPERTIES OF HUMAN URINE

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SUMMARY

This report defines the composition of typical human urine and presents experimental data on its chemical, physical, engineering, and concentrative properties. The effects of chemical and electrolytic pretreatments used in aerospace applications for extraction of potable water are included. The results are presented in tables and plots of unsmoothed data, empirical equations, and tables of nominal values. Sample calculations and examples illustrating the consideration of these data in engineering design applications are included.

INTRODUCTION

The reclamation and reuse of water from human urine is mandatory for long duration space missions due to the severe restrictions imposed on launch weight. Engineering studies show that the equivalent weight of most urine purification equipment is significantly lower than the weight of drinking water that would have to be launched as stored water, if no water recovery system were used (References 1 and 2).

The many different urine purification systems that are under investigation have at least one point in common: all must deal with urine that becomes progressively more concentrated as drinking water is extracted (References 3 through 13). It is clear, therefore, that knowledge of the chemical and physical properties of urine concentrates, for which there is very little reference information, is required for the satisfactory analysis and design of all urine-processing systems. It is hoped that the data reported here will fulfill this need.

The 68 chemical constituents that comprise over 99 percent of the solutes in urine are listed in decreasing order of concentration. A simplified analog of typical urine is presented, consisting of 42 chemical compounds. Data on

variations in urine composition are presented in terms of refractive index, specific conductivity, pH, total dissolved solids, chemical oxygen demand (standard and rapid methods), total Kjeldahl nitrogen, and total organic carbon. The electrolytic pretreatment of urine is described, a mass balance is presented, a discussion of the electrochemistry of the process is given, and a typical composition of electrolyzed urine is listed. The physical properties of urine concentrates were determined in the ranges 4 to 90 percent solutes and 70 to 140 degrees Fahrenheit. Both smoothed and unsmoothed data are presented in tables and plots, which are grouped together at the back of this report. The physical property data presented are the following:

solute weight fraction	solute to water ratio
vapor pressure	osmolality
density	osmolarity
solute concentration	osmotic pressure
water concentration	heat of vaporization
heat of solution	viscosity
specific heat	weight fraction of precipitated solids
surface tension	weight fraction of extracted water
specific conductivity	refractive index
pH	

SYMBOLS

C	= solute concentration, g, of solutes per ml of urine
COD	= chemical oxygen demand, g/l or mg/l
CO ₂ D	= chemical oxygen demand (rapid method), g/l or mg/l
C _p	= specific heat, BTU/lb x ° F
Cw	= water concentration, g of water per ml of urine
Hw	= differential heat of dilution, BTU per lb of water increase
Hs	= differential heat of solution, BTU per lb of solute increase
Hu	= differential heat of vaporization of urine, BTU per pound of urine
k	= specific conductivity, mmho-cm ⁻¹ or μmho-cm ⁻¹
L	= differential heat of vaporization of urine, BTU per pound of water evaporated
Lu	= differential heat of vaporization of urine, BTU per pound of urine
L*	= differential heat of vaporization of water, BTU per pound of water evaporated
M	= apparent average molecular weight of solute particles as calculated from vapor pressure data and Raoult's Law
N	= number of moles of solvent = $\frac{W_w}{18}$
n	= number of moles of solute particles = $\frac{W_s}{M}$
n _i	= refractive index at 70° F relative to air for sodium yellow light
O	= osmolality, apparent g-moles of solute particles per 1000 g of water
Or	= osmolarity, apparent g-moles of solute particles per liter of urine
p	= vapor pressure of urine concentrate, psia
p*	= vapor pressure of pure water, psia

pH	= hydrogen ion concentration, \log_{10} of the reciprocal of the molar concentration of hydrogen ions (H^+)
	$10^{-pH} = \frac{\text{g-moles of hydrogen ions } (H^+)}{\text{liter}}$
R	= gas constant, $8.3144 \frac{\text{Joules}}{\text{g-mole} \times ^\circ K}$
S	= entropy, BTU/lb \times $^\circ F$
T	= temperature, degrees Rankine, Fahrenheit, or Kelvin
TDS	= total dissolved solids, g/Kg or mg/Kg
TKN	= total Kjeldahl nitrogen, g/l or mg/l
TOC	= total organic carbon, g/l or mg/l
\bar{v}	= molar volume of water, $18 \frac{\text{cm}^3}{\text{g-mole}}$
Ww	= weight of solvent, g
Wp	= weight of precipitate, g
Ws	= weight of solutes, g
Wu	= weight of urine, g
x	= solute weight fraction, g of solutes per g of urine
1 - x	= water weight fraction, g of water per g of urine
x_o	= original solute weight fraction, g of solutes per g of urine, initially before concentration
1 - x_o	= original water weight fraction, g of water per g of urine, initially before concentration
y	= weight fraction of extracted water, g of water extracted from urine during concentration per g of initial water content before concentration
1 - y	= weight fraction of unextracted water, g of water in urine concentrate per g of initial water content before concentration
γ	= surface tension, dynes-cm ⁻¹
μ	= dynamic viscosity, centipoise
π	= osmotic pressure, psia
ρ	= density, g of urine per ml of urine

COMPOSITION OF HUMAN URINE

The composition of human urine has been studied by many investigators and the quantities of 158 different chemical constituents are summarized in the NASA Bioastronautics Data Book (Reference 14). These constituents are broadly categorized as electrolytes, nitrogenous compounds, vitamins, hormones, organic acids, and miscellaneous organic compounds. The 68 constituents that have individual maximum concentrations exceeding 10 mg/l are listed in Table I in decreasing order of concentration. These constituents add up to about 36,800 mg/l in typical urine. The remaining 90 compounds total approximately 250 mg/l.

For engineering analysis purposes in water reclamation technologies, an abbreviated list of compounds is in most cases more than adequate to characterize human urine. This is not to suggest that there is any substitute for using real urine in the development and testing of water recovery subsystems; rather, that it is convenient, and sufficiently accurate for most analyses, to use a simplified version of the real thing. An analog for real urine, consisting of 42 compounds, is presented in Table II. The concentrations listed are considered to be typical, and are based on the information in Table I, the measurements presented elsewhere in this report, and the results of numerous chemical analyses of urine made over the last 10 years in the course of developing water recovery subsystems. The 42 out of 158 compounds in Table II account for over 98 percent of the total solute concentration in urine. For most analyses and calculations, Table II should serve as a convenient starting point to develop an even more simplified analog such as Table III, which shows the major categories of (1) inorganic salts, (2) urea, (3) organic compounds, and (4) organic ammonium salts broken down into content of carbon, nitrogen, oxygen, hydrogen, and organic sulfur.

Some measurements that help to broadly categorize urine are presented in Table IV. The measurements were made on 16 different batches of raw, unconcentrated, nonpretreated urine, each containing about 40 liters composed from 20 to 30 male subjects. The total dissolved solids (TDS) of the batches ranged from 24.8 grams per kilogram to 37.1 grams per kilogram.

The measurements selected were considered to be the most significant available for broadly categorizing urine. In addition to the directly measured values of n_i , k , pH, TDS, CO_2D , COD, TKN, and TOC, there are columns of nitrogen and carbon as determined by gas analysis in the electrolytic pretreatment process (see ELECTROLYTIC PRETREATMENT OF HUMAN URINE). The agreement between the two different methods of determination is close for nitrogen, but not so close for carbon. The data in Table IV are plotted in Figures 1 through 8 against TDS. Although a generally increasing trend with increasing TDS is apparent for each parameter except pH, there is considerable deviation from mean values. It is not known how much of the deviation is due to actual variations in the level of the measured quantities, and how much is due to interferences and side reactions involved in the method of measurement. The particular significance of each measurement is discussed below.

Refractive Index (n_i)

The refractive index measurements in this section were made at 70° F with a Bausch and Lomb refractometer calibrated for sodium yellow light relative to air. For a discussion of refractive index of aqueous solutions, see References 15 and 16. For refractive index data on common binary solutions see References 16 and 17. The refractive index has been found to have a straight-line correlation (Figure 12) with solute weight fraction (x) for most species in binary solution. In addition, for many species the effects of solute weight fraction on refractive index are additive.

Specific Conductivity (k)

Specific conductivity is a function of the ionic species present in water. If the amount and identity of each ionic solute is known, then the specific conductivity of a solution can be calculated, as there is a definite relationship between ion concentration and specific conductivity for individual species. The specific conductivity, calculated for the urine listed in Table II, assuming an activity coefficient of 0.74 for each inorganic salt (Reference 17, p. D-93), is $18.0 \text{ mmho-cm}^{-1}$ for the inorganic salts, and approximately 1.5 mmho-cm^{-1} for the organic ammonium salts, for a total of $19.5 \text{ mmho-cm}^{-1}$. This is very close to the values found in real urine (see Figure 2).

pH

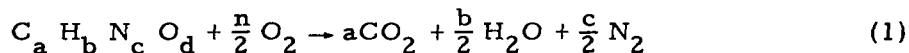
pH is a measure of H^+ and OH^- ions. Usually, in the case of urine, low pH is caused by unbuffered organic acids, and high pH is caused by unbuffered ammonium.

Total Dissolved Solids (TDS)

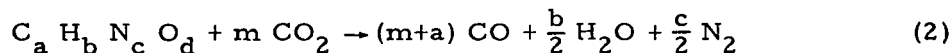
TDS was determined in the same manner as solute weight fraction, i. e., by drying samples at room temperature with a purge flow of $-40^\circ F$ dew point air. TDS is reported in grams per kilogram of solution and is equal to solute weight fraction times 1000. The TDS measurement cannot be expected to match a theoretical calculation of total dissolved solids based on a quantitative knowledge of the species present in urine, because of factors such as volatilization of organic matter, mechanically occluded water, water of hydration, hygroscopic properties of the residue, heat induced chemical decomposition, and oxidation effects. In the case of urine, drying at room temperature minimizes the loss of high vapor pressure solutes such as NH_4HCO_3 , HCl , formic acid, amines and phenols; and results in a TDS figure that is slightly higher than the theoretical value due mainly to water of hydration. As a rule of thumb, it is felt that the TDS value for raw urine in grams per kilogram is approximately equal to the theoretical concentration in grams per liter.

Rapid Method for Chemical Oxygen Demand (CO_2D)

In this method, a microsample is injected into a heated combustion tube (see Reference 18) through which CO_2 is flowing. Reducing materials react with the CO_2 to form CO , which is measured by an infrared analyzer. A generalized equation for oxidation by a combustion process for urine organics is

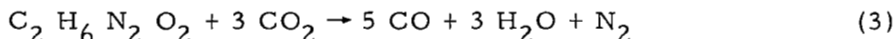


The oxidizing equation for CO_2 is



When both Equations (1) and (2) are balanced in respect to oxygen, then $n = m+a$ and the number of moles of CO produced in Equation (2) is equal to the number of oxygen atoms required in Equation (1). The results are reported as grams per liter of oxygen and are termed "CO₂D".

The mixture of organics in urine per Table II are approximately represented by the equation C₂ H₆ N₂ O₂. The oxidation of this mixture by CO₂ would be



Therefore, in this case, if complete oxidation occurred with no interferences, the total organics in urine would be approximately equal to 90/80 x CO₂D.

The efficiency of oxidation for a number of compounds as reported in Reference 18 is as follows:

Analyses of Known Solutions			
Compound	CO ₂ D, mg/l		Oxidation Efficiency, %
	Calcd	Found	
Acetic acid	246	239	97.2
Benzoic acid	250	248	99.2
Oxalic acid	250	244	97.6
Glycine	250	248	99.2
Urea	250	250	100.0
p-Nitroaniline	250	244	97.6
Phenol	245	216	88.2
Sucrose	248	215	86.7
Acetone	173	145	83.8
Ethanol	235	200	85.1
Methanol	238	205	86.1
Ammonium hydroxide	250	204	80.6
Ammonium chloride	250	274	109.6

Chemical Oxygen Demand (COD)

Chemical oxygen demand is often used as indication of the total organic content of water (Reference 19). It is a measure of the amount of

dichromate that is reduced by oxidation of the organics. Typical COD values for three organic materials are as follows:

Item	COD	
Lactose	0.84 g/g	(Measured)
Glucose	1.07 g/g	(Theoretical, Reference 19)
Potassium Acid Phthalate	1.18 g/g	(Theoretical, Reference 19)

The oxidation of most organic compounds by dichromate is 95 to 100 percent of the theoretical value. However, ammonia, urea, benzene, toluene, and pyridine are among the compounds that are not oxidized by dichromate. Since urine contains large amounts of urea, ammonia and amines, its COD values would be expected to run considerably below the total organic content of urine, and the data presented in Table IV bear this out.

Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl nitrogen (Reference 19) measures organic nitrogen in the trinegative state and includes ammonia nitrogen. TKN would be expected to measure essentially all of the nitrogen in raw urine. When the organics in raw urine are approximately represented by the equation $C_2 H_6 N_2 O_2$, then the total organics would be approximately equal to $90/28 \times \text{TKN}$.

Nitrate and nitrite nitrogen are not measured by TKN and are not present to any appreciable extent in raw urine. However, in electrolyzed urine there can be high levels of nitrate present, and in this case TKN does not indicate total nitrogen.

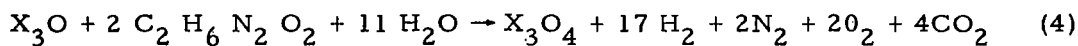
Total Organic Carbon (TOC)

The total organic carbon measurement was made with a Beckman Model 915 Total Organic Carbon Analyzer (see Reference 20). This instrument complies with the ASTM tentative method D2579-T for the determination of organic carbon in water and waste water. A small-size water sample is swept into a catalytic combustion tube (950°C) where all carbonaceous material is oxidized to carbon dioxide. After removal of the water vapor, the CO_2 is introduced into an infrared analyzer sensitized to measure CO_2 . A parallel sample is then injected into a second combustion tube

maintained at a lower temperature (150°C). By this procedure only inorganic carbonates and dissolved CO₂ are liberated. They are swept into the infrared analyzer where they are separately determined. The difference between the total carbon dioxide and the inorganic carbon dioxide is indicative of the organic carbon present in the sample. The method measures essentially all of the carbon in urine. When the organics in urine are approximately represented by the equation C₂ H₆ N₂ O₂, then the total organics in urine would be approximately equal to 90/24 x TOC.

ELECTROLYTIC PRETREATMENT OF HUMAN URINE

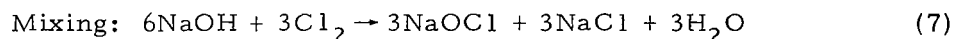
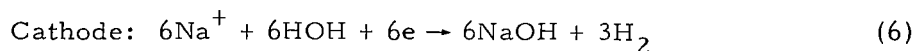
By passing sufficient electricity through human urine, most of the dissolved organic compounds can be converted to hydrogen, oxygen, nitrogen, and carbon dioxide, which are outgassed, leaving behind a semipurified urine that contains primarily inorganic salts. These residual inorganic salts can be removed by electrodialysis to produce potable water. The complete water recovery process is termed electropurification and a typical mass balance is shown in Figure 9. The overall electrochemical reaction is approximately represented as follows:



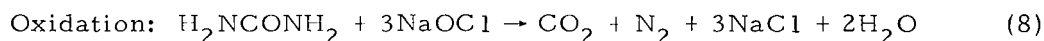
In this equation, X_3O represents the inorganic compounds in raw urine, $C_2 H_6 N_2 O_2$ represents the organic compounds in raw urine, and X_3O_4 represents the inorganic compounds in electrolyzed urine. X represents all atoms other than C, H, N, and O and is considered to have an atomic weight of approximately 30, which is about average for the composition of Table II.

The mechanism for the overall electrochemical reaction is not known. However, it is felt that chemical reactions involving hypochlorite, chlorate, perchlorate, and perhaps both nascent chlorine and nascent oxygen are of prime importance. In actual practice, a batch of urine consisting of approximately 4 liters is circulated through an electrolysis cell operating at a current density in the range 200 to 300 mA/cm² until the TOC, COD, and TKN are each reduced to less than 100 mg/l. The transient behavior of the urine during electrolysis is shown in Figures 10, 11, 12, 13, 14 and 15. These plots are estimates for the typical urine described in Tables II and III, and are based on composited data from approximately 16 test runs. An estimate of the salts remaining after electrolysis is shown in Table V. Essentially all organic material is gone. The organic sulfur is converted to sulfate and most of the original chloride is converted to chlorate and perchlorate. Figures 16, 17, 18 and 19 characterize electrolyzed urine in terms of refractive index, specific conductivity, pH, and TDS respectively. Considerable deviation from mean values is evident.

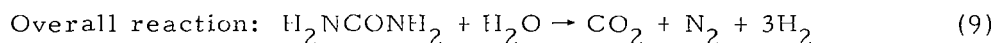
Figures 10 through 15 give some insight into the dynamics of the organic removal process. In the first few minutes of electrolysis there is an induction period in which the chloride level drops about 10% (Figure 10). Conversion of chloride to hypochlorite according to the following reaction is indicated:



During the first 3 hours of electrolysis, the outgassing of oxygen is low (Figure 14), indicating that little if any excess water is being electrolyzed. The ratio of nitrogen to carbon (Figure 15) is higher than the average value for urine, indicating that urea and other high-nitrogen organics are being oxidized in preference to low- and zero-nitrogen organics such as the organic acids. The fact that COD, which does not include urea, is decreasing (Figure 10) indicates that other organics besides urea are also being oxidized. The primary chemical reaction appears to be hypochlorite oxidation, which, for urea, is mainly as follows:

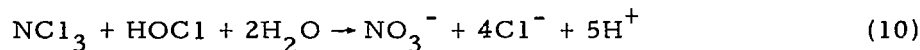


The overall reaction, combining Equations (5), (6), (7), and (8) would be as follows:



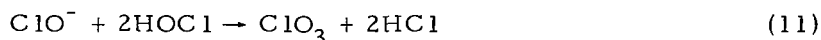
Between hour 3 and hour 4 the chloride level drops, indicating a higher concentration of hypochlorite and the preferential oxidation of a new group of organic compounds. The decline in pH (Figures 10 and 15) indicates that ammonium ions are also being removed, leaving the organic acids unbuffered. By hour 4 the organic nitrogen (TKN, Figure 10) has dropped to almost zero and the nitrogen to carbon ratio (Figure 15) is below the average value. The nitrogen compounds that remain in solution as zero TKN is approached were identified as mainly nitrogen trichloride, NCl_3 , and nitrate ion, NO_3^- .

NCl_3 is detected by TKN, but NO_3^- is not. NCl_3 is an end product of the hypochlorite oxidation of urea (Reference 21). For simplicity, it is not shown in Equation (8), which represents the primary reaction of hypochlorite with urea. NCl_3 can be converted to NO_3^- by hypochlorite as follows:

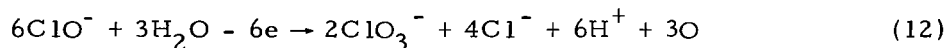


It was found that in low voltage electrolysis (current density $< 2 \text{ mA/cm}^2$) large concentrations ($\sim 5 \text{ g/l}$) of NO_3^- did occur, but in high voltage electrolysis (current density $> 150 \text{ mA/cm}^2$) the NO_3^- concentration remained low ($< 40 \text{ mg/l}$). It was also found that the organic acids that remain in solution at this point in the process are mainly formic (HCOOH) and acetic ($\text{CH}_3\text{CO}_2\text{H}$) acids. These free aliphatic acids are the products of hypochlorite and N-chloro compound reactions with the organic materials other than urea. Low-voltage electrolysis does not remove these residual organic acids. The addition of a catalyst during low voltage electrolysis reduced the residual NO_3^- level, but did not reduce the level of residual organic acids.

Between hour 4 and hour 5 of high voltage electrolysis, the chloride level continues to drop (Figure 10), indicating a continuing conversion to hypochlorite. Also, the rapid drop in refractive index as it is compared to TDS (Figure 12) indicates a conversion of hypochlorite to chlorate, which was verified by laboratory analysis. Chlorate can be produced by the following reaction that occurs in acid solutions (see References 22 and 23):



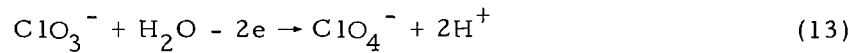
Chlorate can also be produced by anodic oxidation (References 22 and 23) as follows:



The increase in oxygen production (Figure 14) would argue that Equation (12) predominates. Also during this period the pH (Figure 15) begins to rise, indicating that the residual organic acids are being oxidized. This oxidation process might involve the nascent oxygen that is produced in Equation (12), or it might be a direct electrolytic decomposition at the anode.

It probably does not involve the chlorate ion, which is not as good an oxidizer as hypochlorite. Also, nitrogen continues to be evolved (Figure 14) indicating the removal of unidentified residual nitrogen-containing compounds.

Between hour 5 and hour 6 the pH completes its rise to pH = 7, and the organic level falls to below 500 mg/l (Figure 10). Since nearly all of the chloride was converted to chlorate by the beginning of the fifth hour, the n_i vs TDS data (Figure 12) indicate that chlorates are being converted to perchlorates by anodic oxidation as follows:



Between hour 6 and hour 7 the organic level is reduced to less than 100 mg/l, while more perchlorates are produced. At hour 7 the organic level is low enough that subsequent processing by electrodialysis produces water that meets all of the NAS/NRC chemical potability standards (Reference 24).

PHYSICAL PROPERTIES OF HUMAN URINE CONCENTRATES

The physical properties reported in this section were determined for the mixed urine of 40 to 50 male subjects over a period of several months. Seven batches of urine, containing 19 liters per batch, were each concentrated by evaporation to approximately 200 milliliters, at which point the liquors of similarly pretreated batches were mixed and concentrated further. The physical properties were measured at discrete intervals during the concentration process. The unsmoothed data are presented in Table VI. Four different chemical pretreatments were investigated as follows:

- $\text{H}_2\text{SO}_4 + \text{CrO}_3$
- $\text{H}_2\text{SO}_4 + \text{CrO}_3 + \text{CuSO}_4$
- $\text{Ca}(\text{ClO})_2$
- Electrolytic (see ELECTROLYTIC PRETREATMENT OF HUMAN URINE)

Pretreatments are used in most urine processing systems (References 2 and 25) to stabilize urine with respect to microbes, odors, and free ammonia. These four pretreatments are the most widely used. Physical property data were not obtained for untreated urine because bacterial action always developed within the first few days of the one- to two-month period in which the progressive concentration of the urine and physical measurements were made. This bacterial action resulted in the decomposition of urea and the evolution of large amounts of ammonia.

Most of the physical properties are not sensitive to the first three pretreatments, in which less than 10 g per liter of chemical are involved. Only precipitate, viscosity, and pH are noticeably affected. The electrochemical pretreatment which converts most of the organic material in urine to useful cabin gases has a noticeable impact on many of the concentrative properties, but not on vapor pressure and the other colligative properties.

Symbols are assigned in Table VI to each batch of urine, and these symbols are used consistently through this section. Deviations in the data can be readily determined from the individual plots that are presented in each section.

Nominal values for the physical properties, which are intended for use in engineering calculations are presented in Tables VII, VIII, and IX. The following examples are given to illustrate the usefulness of these data and to underscore several often-neglected design considerations.

Example 1, Vapor Compression System

In a vapor compression system, latent heat is conserved by compressing the evolved water vapor to a higher pressure. This allows it to condense at a temperature that is higher than the boiling temperature of urine, thereby making possible the transfer of latent heat from the condensing vapor to the boiling urine. This thermodynamic process is illustrated on a T-S diagram in Figure 20 and is summarized as follows:

- 1-2: Boiling of urine, heat received from condensing vapor
- 2-4: Compression of vapor from boiling pressure to a higher condensing pressure (2-4 is for boiling of pure water; 2'-4' and 2''-4'' are for boiling of urine concentrates)
- 4-5-6: Cooling and condensing of vapor, heat rejected to boiling urine.

As the urine, which is fed to and contained within a vapor compression system, becomes more and more concentrated due to the extraction of water, its vapor pressure decreases as shown in Table VIII. The pressure ratio required to raise the pressure of the evolved vapor to a level at which its condensing temperature is just equal to the boiling temperature of the concentrated urine (illustrated in Figure 20 by the paths 2'-3' and 2''-3'') is easily calculated from Table VIII. It is simply the ratio of the vapor pressure at $x = 0$ to that at x . For any x , this ratio is very nearly the same in the range 80° F to 140° F. The ratio is plotted in Figure 21.

Combining the data in Figure 21 with those in Figure 49 results in Figure 22, a plot that shows the pressure ratio versus the weight fraction of extracted water.

Figure 22 is useful when evaluating the point at which it is no longer beneficial to increase pressure ratio and hence compressor weight and power for the sake of obtaining higher water recovery efficiencies. When

evaluations such as these are made, other factors that also directly or indirectly influence pressure ratio and are a function of the amount of water extracted, such as scaling due to precipitate formation and changes in transport properties, must also be evaluated.

Example 2, Vacuum Distillation System

The designer is concerned with establishing optimum boiling and condensing temperatures on the basis of heat and mass transfer with a vacuum distillation system, as with any distillation system including vapor compression. The rise in the boiling point of urine that accompanies higher concentrations must not be ignored. The increase in boiling point as a function of water extracted is shown in Figure 23 and is obtained by combining data from Figures 30 and 49.

Example 3, Reverse Osmosis System

In a reverse osmosis system, the pressure applied to the urine must exceed the osmotic pressure in order to achieve a reverse osmotic flow of water. As water is extracted, the osmotic pressure of the remaining concentrate increases as shown in Figure 24, which was obtained by combining Figures 38 and 49.

The required increase in osmotic pressure to achieve a higher water recovery efficiency represents an increase in weight and power, so for any mission there is an optimum operating pressure.

Example 4, Miscellaneous Considerations

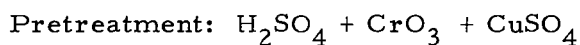
Several designers have proposed urine distillation systems in which urine would be continually fed into an evaporator compartment and precipitates would be continually separated and withdrawn. Presumably this proposition is based on the mistaken belief that urine behavior is similar to that of a binary solution such as sodium chloride and water, in which the brine does not concentrate beyond the solubility limit of sodium chloride. However, urine does not behave like this. Due to the presence of many highly soluble and even some liquid species such as citric, formic, and lactic acids, urine

continues to get more and more concentrated as water is extracted, even as certain species are being precipitated. This behavior is indicated in Figure 47.

In most of the systems that have been proposed for extracting water from urine, the extraction process is discontinued before 100 percent of the water is removed, i. e., before complete dryness is reached. This leaves the task of transferring the mother liquor, including entrained precipitates, from the water removal area to a holding or storage area. The viscosity and precipitate data contained here should be helpful in the design of transfer systems, and density data should aid in sizing the volume required for storing the mother liquor.

The calculations required to obtain these kinds of precipitate and volume information are illustrated in the following example.

Assume urine with the following initial conditions:



$$x_o = .042$$

$$\rho_o = 1.012$$

Calculate the amount of precipitate contained in the urine concentrate slurry that remains after extraction of 98 percent of the water from a liter of urine with the above listed initial conditions. Also calculate the slurry's volume.

From Figure 48 for $y = .98$; $x = .665$

From Figure 32 for $x = .665$; $\rho = 1.312$

From Figure 47 for $x = .665$; $\frac{W_p}{W_{s_o}} = .11$

$$W_{u_o} = \rho_o V_o = 1.012 (1000) = 1012 \text{ g}$$

$$W_{s_o} = x_o W_{u_o} = .042 (1012) = 42.5 \text{ g}$$

$$W_p = \frac{W_p}{W_{s_o}} W_{s_o} = .11 (42.5) = 4.675 \text{ g}$$

$$V_p = W_p / \rho_p = 4.675 / 1.470 = 3.18 \text{ ml}$$

(from Figure 32 at $x = 1.0$, $\rho_p = 1.470$)

$$W_s = W_{s_o} - W_p = 42.5 - 4.675 = 37.82 \text{ g}$$

$$W_u = W_s / x = 37.85 / .665 = 56.84$$

$$V_u = W_u / \rho = 56.84 / 1.312 = 43.32 \text{ ml}$$

$$\text{weight of precipitate} = W_p = 4.675 \text{ g}$$

$$\text{weight of slurry} = W_u + W_p = 56.84 + 4.675 = 61.52 \text{ g}$$

$$\text{volume of slurry} = V_u + V_p = 43.32 + 3.18 = 46.50 \text{ ml}$$

Similar calculations for other pretreatments and various degrees of water extraction enabled construction of Figures 25 and 26.

Systems that require the removal and storage of a mother liquor need a simple way of monitoring the progress of the water extraction process to determine the proper end point. Refractive index, Figure 50 deviates less between different batches of urine and different pretreatments than any other physical property. In addition, the measurement is relatively easy to make and requires only a smear of sample. It would be a relatively simple, direct, and accurate means of monitoring and controlling water recovery processes.

Solute Weight Fraction

Solute weight fraction is the total weight of dissolved substances in urine per unit weight of urine. It does not include precipitated solids. As urine is concentrated, some of the original solids are normally precipitated, as shown in Figure 47. The solute weight fraction includes only those species which remain in solution. It was determined by drying an aliquot of concentrate to approximately a -40° F dew point with a dry air purge at room temperature. With this technique there is a minimal loss of high vapor pressure solutes such as NH_3 , CO_2 , HCl , formic acid, amines, and phenols. Solute weight fraction is the property against which all of the other physical properties are correlated.

Vapor Pressure

Vapor pressure was determined with an Othmer vapor-liquid equilibrium still (Reference 26). The data were smoothed in a two-step procedure in which Raoult's law was utilized. First, the apparent average molecular weight of solute particles, M , was calculated with Raoult's equation and the values were plotted against the boiling temperature, T , of the urine concentrate. The apparent average molecular weight is equal to the true average molecular weight of solute particles only at infinite dilution where intermolecular actions between solute particles is minimal. The term "particle" includes both molecules and ions and is a necessary distinction because a mole of ions lowers vapor pressure as much as a mole of undissociated molecules. The equation used to compute M is derived as follows:

Raoult's law states that the ratio of the amount of vapor pressure lowering to the vapor pressure of the pure solvent is equal to the ratio of the number of moles of solute particles to the number of moles of solution:

$$\frac{p^* - p}{p^*} = \frac{n}{N + n}$$

Rearranging terms:

$$\frac{p}{p^*} = \frac{N}{N + n}$$

$$\frac{p^* - p}{p} = \frac{n}{N} = \frac{Ws/M}{Ww/18} = \frac{x}{1 - x} \frac{18}{M}$$

$$M = 18 \frac{x}{1 - x} \frac{p}{p^* - p}$$

where:

p^* = vapor pressure of solvent

p = vapor pressure of solution

Ws = weight of solute

Ww = weight of solvent

N = number of moles of solvent = $\frac{Ww}{18}$

n = number of moles of solute particles = $\frac{Ws}{M}$

M = apparent average molecular weight of solute particles

x = solute weight fraction

T = boiling temperature of urine

The values for x, p, and T were measured. p* was obtained from published data (Reference 27).

For most urine samples the plot of M vs T had a small negative slope with the following mean value:

$$\frac{dM}{dT} = -0.1145$$

The second step in the two-step procedure for smoothing vapor pressure data was carried out next. From the plots of M vs T, M at 100° F was plotted against the solute fraction, x, as shown in Figure 27.

The nominal line shown in Figure 27 was then fitted, and points from it were used as input to a computer program that calculated the nominal values of vapor pressure and the other colligative properties that are presented in Tables VII, VIII and IX.

The following equations were used:

$$p = \frac{p^*}{\left(\frac{18}{M} \frac{x}{1-x}\right) + 1}$$

$$M_T = M_{100} - 0.1145 (T-100)$$

where:

T = degrees Fahrenheit

and all other parameters are as previously defined.

This method of smoothing vapor pressure data is advantageous for computing the colligative properties as compared to standard smoothing techniques such as plotting of Dürhing lines and graphing $\ln p$ versus $\ln p^*$.

In addition to the table of nominal vapor pressures, Table VII, the smoothed vapor pressure data are presented in three familiar forms in Figures 28, 29, and 30. In figure 31, vapor pressure data are compared to the smoothed values and to the measured values of urea and sodium chloride solutions.

Density

Density was calculated from specific gravity measurements made with precision grade hydrometers. The data are plotted in Figure 32.

Most of the chemically treated urines scatter around a mean line within approximately $\pm 1 \frac{1}{2}$ percent. This mean line is described by the following equation:

$$\rho = 0.4775 x + 0.99325$$

where:

ρ = density, g of urine per ml of urine

x = solute weight fraction, g of solutes per g of urine

The density of the electrolytically treated urine is greater for a given solute fraction than chemically treated urine due to a substantial loss of organic solutes. It is expressed by the following equation (for the lower curve in Figure 32, which is for treatment at low current density):

$$\rho = 0.6110 x + 0.9904$$

where:

ρ = density, g of urine per ml of urine

x = solute weight fraction, g of solutes per g of urine

The density of urine treated electrolytically at high current density is not a straight line. The curve in Figure 32 may be used.

Solute Concentration

The solute concentration, C , is the weight of solutes per unit volume of urine and is calculated as follows:

$$C = \rho x$$

where:

C = solute concentration, g of solutes per ml of urine

ρ = density, g of urine per ml of urine

x = solute weight fraction, g of solutes per g of urine

The nominal variation of solute concentration at 70° F with solute weight fraction is shown in Figure 33.

Water Concentration

The water concentration, C_w , is the weight of water per unit volume of urine. C_w is equal to the difference between density and solute concentration, and is calculated as follows:

$$C_w = \rho - c = \rho (1 - x)$$

where:

C_w = water concentration, g of water per ml of urine

ρ = density, g of urine per ml of urine

C = concentration, g of solutes per ml of urine

x = solute weight fraction, g of solutes per g of urine

The nominal variation of water concentration at 70° F with solute weight fraction is shown in Figure 34.

Solute to Water Ratio

The solute to water ratio is the weight of solutes per unit weight of water, and is equal to:

$$\frac{x}{1 - x}$$

where:

$$\frac{x}{1 - x} = \text{g of solute per g of water}$$

$$x = \text{solute weight fraction, g of solute per g of urine}$$

$$1 - x = \text{water weight fraction, g of water per g of urine}$$

The variations of solute to water ratio with solute weight fraction is independent of the pretreatment used and is shown in Figure 35.

Osmolality

Osmolality is analogous to molality. The difference is that in osmolality, the apparent average molecular weight of solute particles as determined by measuring vapor pressure depression and applying Raoult's law, is used instead of the average molecular weight of solute molecules. The distinction between particles and molecules is important; so too is the relationship of osmolality to vapor pressure depression. For further discussion see the Vapor Pressure paragraphs.

Osmolality is defined as the number of apparent g-moles of solute particles (as calculated from vapor pressure data) per 1,000 g of solvent:

$$\begin{aligned} O &= \frac{n}{W_w} 1000 = \frac{W_s/M}{W_w} 1000 \\ &= \frac{x}{1 - x} \frac{1000}{M} = \frac{p^* - p}{p} \frac{1000}{18} \end{aligned}$$

where:

O = osmolality, apparent g-moles of solute particles per 1000 g of water

n = number of solute particles = $\frac{W_s}{M}$

W_s = weight of solute, g

M = apparent average molecular weight of solute particles

W_w = weight of water, g

x = solute weight fraction, g of solutes per g of urine

p* = vapor pressure of water, psia

p = vapor pressure of urine, psia

The variation of osmolality at 100° F with solute weight fraction is shown in Figure 36.

Osmolarity

Osmolarity is analogous to molarity in the same way osmolality is analogous to molality. Refer to Osmolality paragraphs.

Osmolarity is defined as the number of apparent g-moles of solute particles (as calculated from vapor pressure data) per liter of solution:

$$\begin{aligned} Or &= \frac{n}{W_u} \rho \ 1000 = \frac{W_s/M}{W_u} \rho \ 1000 \\ &= \frac{x \rho}{M} \ 1000 = \frac{C}{M} \ 1000 \\ &= \frac{p^* - p}{p} \frac{1000}{18} \rho (1 - x) \\ &= \rho (1 - x) O = (\rho - C) O = C_w O \end{aligned}$$

where:

Or = osmolarity, apparent g-moles of solute particles per liter of urine

O = osmolality, apparent g-moles of solute particles per 1,000 g of water

$$n = \text{number of moles of solute particles} = \frac{W_s}{M}$$

$$W_s = \text{weight of solute, g}$$

$$M = \text{apparent average molecular weight of solute particles}$$

$$W_u = \text{weight of urine, g}$$

$$\rho = \text{density of urine, g of urine per ml of urine}$$

$$C = \text{solute concentration, g of solutes per ml of urine}$$

$$C_w = \text{water concentration, g of water per ml of urine, } = \rho - C$$

$$x = \text{solute weight fraction, g of solutes per g of urine}$$

$$p^* = \text{vapor pressure of water, psia}$$

$$p = \text{vapor pressure of urine, psia}$$

The variation of osmolarity at 100° F with solute weight fraction is shown in Figure 37 for chemically pretreated urine.

Osmotic Pressure

Osmotic pressure is estimated from the vapor pressure data. In practice such estimates are found to approximate closely experimental values to osmolarities of 5 and beyond (Reference 28). The osmotic pressure was calculated at 100° F as follows:

$$\begin{aligned}\pi &= a \frac{RT}{\bar{v}} \ln \frac{p^*}{p} \\ &= 20,836 \ln \left(\frac{p^* - p}{p} + 1 \right)\end{aligned}$$

where:

$$\pi = \text{osmotic pressure, psia}$$

$$R = \text{gas constant, } 8.3144 \frac{\text{Joules}}{\text{g-mole} \times ^\circ\text{K}}$$

$$T = \text{temperature, } 311^\circ\text{K (100}^\circ\text{ F)}$$

\bar{v} = molar volume of water, $18 \frac{\text{cm}^3}{\text{g-mole}}$

a = $1.4504 \times 10^{-5} \frac{\text{psia}}{\text{dyne-cm}^2}$

p^* = vapor pressure of water at 100° F , psia

p = vapor pressure of urine at 100° F , psia

The variation of osmotic pressure with solute weight fraction is shown in Figure 38.

Differential Heat of Vaporization

The following relationship between vapor pressure and heat of vaporization is derived (Reference 29) by integration of the Clausius-Clapeyron equation:

$$\ln p = L/L^* \ln p^* + c$$

where:

p = vapor pressure of urine, psia

p^* = vapor pressure of water, psia

L = differential heat of vaporization of urine, BTU per lb of water evaporated

L^* = heat of vaporization of pure water, BTU per lb of water evaporated

c = constant of integration

The nominal values for L that are shown in Table IX were calculated by evaluating the above equation, over the range 80° F to 144° F , at two different pressures separated by an increment corresponding to 4° F . The calculation is made as follows:

$$\ln p_2 = L/L^* \ln p_2^* + c$$

$$\ln p_1 = L/L^* \ln p_1^* + c$$

subtracting:

$$\ln p_2 - \ln p_1 = L/L^* (\ln p_2^* - \ln p_1^*)$$

$$L/L^* = \frac{\ln(p_2/p_1)}{\ln(p_2^*/p_1^*)}$$

The differential heat of vaporization, L , is the heat required to remove a unit quantity of water from urine with an infinitesimal increase in concentration. The differential heat of vaporization, Lu , which would be required to vaporize all of the water in a unit quantity of urine without changing concentration is calculated as follows:

$$Lu = (1 - x) L$$

where:

Lu = differential heat of vaporization of urine, BTU/lb of urine

L = differential heat of vaporization of urine, BTU/lb of water

$1 - x$ = weight fraction of water, lb of water per lb of urine

Water cannot, of course, be vaporized from urine without a change in concentration. The heat required to effect an evaporative increase in concentration is called the integral heat of vaporization, and can be evaluated by using an average value for the differential heat of vaporization in the interval of concentration under consideration.

A computer program was used to calculate nominal values of L and Lu using vapor pressure and enthalpy data for pure water (Reference 27) at 4° F increments, and the equations for vapor pressure that are given in the Vapor Pressure paragraphs. Nominal values are tabulated in Table IX. The variation with solute weight fraction for one temperature is shown in Figure 39.

Differential Heat of Solution

The differential heat of solution and the differential heat of dilution are defined in Reference 28 as follows:

Differential heat of solution is the heat absorbed when a unit quantity of solute is added to a very large quantity of solution at a specified concentration.

Differential heat of dilution is the heat absorbed when a unit quantity of solvent is added to a very large quantity of solution at a specified concentration.

The relationship between these two quantities is readily derived by considering the case in which solvent and solute are added in a proportion that causes no change in concentration. For this case the net change in energy of the solution is zero; therefore:

$$\Delta W_w H_w + \Delta W_s H_s = 0$$

and for no change in concentration, the solvent and solute must be added in the following proportion:

$$\frac{\Delta W_w}{\Delta W_s} = \frac{1 - x}{x}$$

These two expressions combine as follows:

$$H_s = -H_w \frac{1 - x}{x}$$

where:

H_s = differential heat of solution, BTU per lb of solute increase

H_w = differential heat of dilution, BTU per lb of water increase

ΔW_w = water increase, lb

ΔW_s = solute increase, lb

$\frac{1 - x}{x}$ = ratio of water to solutes, lb of water per lb solute

Applying the first law of thermodynamics to the process of vaporizing water from a urine solution the following relationship is derived:

$$H_w = L^* - L$$

where:

H_w = differential heat of dilution, BTU per lb of water increase

L^* = heat of vaporization of pure water, BTU per lb of water evaporated

L = differential heat of vaporization of urine, BTU per lb of water evaporated

The above expressions were used to compute the nominal values of H_s and H_w that are presented in Tables VII and IX. Their variation with solute weight fraction is shown in Figure 40 and 41 respectively.

Specific Heat

The specific heat is presented in Figure 42 and was obtained from Reference 30. Nominal values are listed in Table VII.

Surface Tension

Surface tension was measured by the capillary rise method (Reference 31). Nominal values of surface tension are presented in Table VII. The data are plotted in Figure 43.

Specific Conductivity

The specific conductivity was measured with a small platinum electrode cell of about 5 ml capacity with a cell constant of 10 cm^{-1} . Nominal values of specific conductivity are presented in Table VII. The data are plotted in Figure 44.

Viscosity

Viscosity was measured with an Ostwald viscometer (Reference 28 and 32). Nominal values are presented in Table VII. The data are plotted in Figures 45 and 46. The following empirical relationships were found:

For $x < 0.5$:

All pretreatments:

$$\mu = 0.9 e^{\frac{3}{2} \left(\frac{x}{1-x} \right)}$$

For $X > 0.5$:

$\text{Ca}(\text{ClO})_2$ pretreatment:

$$\mu = \frac{8}{7} e^{\frac{5}{4} \left(\frac{x}{1-x} \right)}$$

$\text{H}_2\text{SO}_4 + \text{CrO}_3$ pretreatment:

$$\mu = 1.8 e^{\frac{4}{5} \left(\frac{x}{1-x} \right)}$$

where:

μ = dynamic viscosity, centipoise

x = solute weight fraction, g of solutes per g of urine

$1-x$ = water fraction, g of water per g of urine

Weight Fraction of Precipitated Solids

The amount of precipitate was determined by filtering all suspended and precipitated solids from a urine sample of known size and composition. The amount of dried precipitate is reported as a fraction of the original solute content. The following definition is made:

$$\text{Weight Fraction of Precipitated Solids} = \frac{W_p}{W_s_o} = \frac{\text{g of dry precipitate}}{\text{g of original solute content}}$$

The data are presented in Figure 47. There is little variance in the $\text{H}_2\text{SO}_4 + \text{CrO}_3$ pretreatment data. $\text{Ca}(\text{ClO})_2$ and electrolytic pretreatment data have a wider spread. Nominal values are presented in Table VII.

Weight Fraction of Extracted Water

The weight fraction of extracted water is defined as the amount of water removed from urine during dehydration per unit weight of the original water content. The following algebraic relationship applies:

$$y = 1 - \left(1 - \frac{W_p}{W_{s_o}} \right) \frac{x_o}{1 - x_o} \frac{1 - x}{x}$$

where:

- y = Weight fraction of extracted water, g of water extracted from urine per g of original water content
- x = solute weight fraction, g of solutes per g of urine
- $1 - x$ = water weight fraction, g of water per g of urine
- x_o = original solute weight fraction, g of original solutes per g of original urine
- $1 - x_o$ = original water weight fraction, g of original water per g of original urine
- $\frac{W_p}{W_{s_o}}$ = weight fraction of precipitated solids, g of dry precipitate per g of original solute content
- $1 - \frac{W_p}{W_{s_o}}$ = weight fraction of remaining solutes, g of solutes per g of original solute content

The data are presented in Figure 48. Nominal values are presented in Table VII and in Figure 49, which shows the weight fraction of extracted water as a function of solute weight fraction for $x_o = 0.04$.

Refractive Index

The refractive index determinations were made at 70° F with an Abbe refractometer calibrated for sodium yellow light relative to air. The data are plotted in Figure 50 and show a straight-line relationship between refractive index and solute weight fraction up to about $x = 0.51$. At this point the slope of the line increases abruptly. Refractive index may be used to calculate nominal values of x with the following empirical equations. Nominal values of n_i are listed in Table VII.

For $x < 0.51$:

$$x = 6.29371 n_i - 8.38545$$

For $x > 0.51$:

$$x = 4.12655 n_i - 5.32242$$

where:

x = solute weight fraction, g of solute per g of urine

n_i = refractive index at 70° F relative to air for sodium yellow light

The refractive index is often plotted in the following form as shown in Figure 51:

$$\frac{1}{\rho} \frac{n^2 - 1}{n^2 + 2}$$

where:

ρ = density, g of urine per ml of urine

n_i = refractive index at 70° F relative to air for sodium yellow light

There are theoretical reasons (Reference 14) why this parameter should exhibit linear dependence on solute weight fraction. It is interesting that except for the high current density electrolytic pretreatment, the parameter

remains within ± 4 percent of the value 0.2020, for $0 < x < 0.90$, and within this narrow range it varies in straight-line relationships.

pH

pH was measured electrometrically at 70° F with a Beckman Expanded Scale pH meter. The data show that pH is primarily a function of initial pH and pretreatment. Concentration causes pH to change but little from its initial value. The data are plotted in Figure 52.

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Table I
CONSTITUENTS OF HUMAN URINE EXCEEDING 10 mg/l. FROM REFERENCE 12

Item	Formula	Formula Weight	mg/l	Range mg/l	Solubility Limit In A Binary Solution g/100g H ₂ O
Total Solutes			36,700	46,700	---
Urea	H ₂ NCONH ₂	60.1	9,300	23,300	119
Chloride	Cl ⁻	35.5	1,870	8,400	---
Sodium	Na ⁺	23.0	1,170	4,390	---
Potassium	K ⁺	39.1	750	2,610	---
Creatinine	C ₄ H ₇ N ₃ O	113.1	670	2,150	8.7
Sulfur, Inorganic	S	32.1	163	1,800	---
Hippuric Acid	C ₆ H ₅ CO·NHCH ₂ ·CO ₂ H	179.2	50	1,670	0.367
Phosphorus, Total	P	31.0	470	1,070	---
Citric Acid	HOC(CH ₂ CO ₂ H) ₂ CO ₂ H	192.1	90	930	208
Glucuronic Acid	C ₆ H ₁₀ O ₇	194.1	70	880	S.
Ammonia	NH ₃	17.0	200	730	---
Uric Acid	C ₅ H ₄ O ₃ N ₄	168.1	40	670	0.00645
Uropepsin (as Tyrosine)	HO·C ₆ H ₄ ·C ₂ H ₃ (NH ₂)·CO ₂ H	181.2	70	560	0.04
Bicarbonate	HCO ₃ ⁻	61.0	20	560	---
Creatine	HN:C(NH ₂)N(CH ₃)·CH ₂ ·CO ₂ H·H ₂ O	149.2	0	530	1.4
Sulfur, Organic	S	32.1	77	470	---
Glycine	NH ₂ ·CH ₂ ·CO ₂ H	75.1	90	450	23
Phenols	C ₆ H ₅ ·OH	94.1	130	420	8.2
Lactic Acid	CH ₃ ·CHOH·CO ₂ H	90.1	30	400	∞
Calcium	Ca ⁺²	40.1	30	390	---
Histidine	C ₃ H ₃ N ₂ ·CH ₂ ·CH·(NH ₂)·CO ₂ H	155.2	40	330	S.
Glutamic Acid	HO ₂ C·CHNH ₂ ·(CH ₂) ₂ ·CO ₂ H	147.1	<7	320	1.5
Androsterone	C ₁₉ H ₃₀ O ₂	290.5	2	280	1.;S.
1-Methylhistidine	C ₃ H ₃ N ₂ CH ₂ CH(NH·CH ₃)·COOH	169.2	30	260	
Magnesium	Mg	24.3	20	205	---
Imidazole Derivatives	C ₃ H ₄ N ₂	68.1	90	200	S.
Glucose	C ₆ H ₇ O ₆ (COCH ₃) ₅	390.4	30	200	0.15
Taurine	NH ₂ ·CH ₂ ·CH ₂ ·SO ₃ H	125.2	5	200	6.4
Aspartic Acid	C ₄ H ₇ O ₄ N	133.1	<7	170	2.71
Carbonate	CO ₃ ⁻²	60.0	100	150	---
Cystine	[HO ₂ C·CH(NH ₂)·CH ₂ S·] ₂	240.3	7	130	0.01
Citrulline	NH ₂ CONH(CH ₂) ₃ ·CH·(NH ₂)·CO ₂ H	175.2	0	130	S.
Threonine	C ₄ H ₉ O ₃ N	119.1	10	120	S.
Lysine	(NH ₂) ₂ C ₅ H ₉ ·CO ₂ H	146.2	5	110	V.S.
Indoxylsulfuric Acid	C ₈ H ₇ ON·H ₂ SO ₄	231.2	3	110	
m-Hydroxyhippuric Acid	C ₈ H ₄ COHC(CONH·CH ₂ COOH)	195.2	1	100	
p-Hydroxyphenyl-Hydroxylic Acid			1	100	

Table I
CONSTITUENTS OF HUMAN URINE EXCEEDING 10 mg/l. FROM REFERENCE 12 (Concluded)

Item	Formula	Formula Weight	mg/l	Range mg/l	Solubility Limit In A Binary Solution g/100g H ₂ O
Aminoisobutyric Acid	$\text{H}_2\text{N}\cdot\text{CH}_2\text{CH}(\text{CH}_3)\cdot\text{COOH}$	103.1	3	120	
Inositol	$\text{C}_6\text{H}_{12}\text{O}_6$	180.2	5	100	
Formic Acid	$\text{H}\cdot\text{CO}_2\text{H}$	46.0	20	90	∞
Urobilin	$\text{C}_{33}\text{H}_{40}\text{O}_6\text{N}_4$	588.7	7	90	
Tyrosine	$\text{HO}\cdot\text{C}_6\text{H}_4\cdot\text{C}_2\text{H}_3(\text{NH}_2)\cdot\text{CO}_2\text{H}$	181.2	10	70	0.04
Pyruvic Acid	$\text{CH}_3\cdot\text{CO}\cdot\text{CO}_2\text{H}$	88.1	2	70	∞
Albumin			7	70	
Asparagine	$\text{HO}_2\text{C}\cdot\text{CH}(\text{NH}_2)\cdot\text{CH}_2\cdot\text{CONH}_2$	132.1	20	70	3.1
Tryptophan	$\text{C}_6\text{H}_4\cdot\text{NH}\cdot\text{CH}(\text{C}\cdot\text{C}_2\text{H}_3(\text{NH}_2)\text{CO}_2\text{H})$	286.8	5	60	25
Ketones (as Acetone)	CH_3COCH_3	58.1	10	50	∞
Serine	$\text{HO}\cdot\text{CH}_2\cdot\text{CHNH}_2\cdot\text{CO}_2\text{H}$	105.1	20	50	4
Alanine	$\text{H}_2\text{N}\cdot\text{CH}(\text{CH}_3)\cdot\text{CO}_2\text{H}$	89.1	15	50	20.5
Purine Bases	$\text{C}_5\text{H}_4\text{N}_4$	120.1	0	50	i.
Glycocyamine			15	45	
Proline	$\text{HN}\cdot(\text{CH}_2)_3\cdot\text{CH}\cdot\text{CO}_2\text{H}$	115.1	<7	40	V.S.
Arginine	$\text{H}_2\text{N}\cdot\text{C}(\text{:NH})\cdot\text{NH}\cdot(\text{CH}_2)_3\cdot\text{CH}(\text{NH}_2)\cdot\text{CO}_2\text{H}$	174.2	<7	40	15
Ascorbic Acid	$\text{C}_6\text{H}_8\text{O}_6$	176.1	3	40	V.S
Oxalic Acid	$\text{HO}_2\text{C}\cdot\text{CO}_2\text{H}$	90.0	1	30	10
Bilirubin	$\text{C}_{33}\text{H}_{36}\text{N}_4\text{O}_6$	584.7	3	30	i.
Valine	$(\text{CH}_3)_2\text{CH}\cdot\text{CH}(\text{NH}_2)\cdot\text{COOH}$	117.2	<7	30	
Phenylalamine	$\beta\cdot\text{C}_6\text{H}_5\cdot\text{CH}_2\cdot\text{CH}(\text{NH}_2)\cdot\text{COOH}$	165.2	6	30	
Allantoin	$\text{C}_4\text{H}_6\text{O}_3\text{N}_4$	158.1	2	25	0.76
Oxoglutaric Acid	$\text{C}_5\text{H}_6\text{O}_5$	146.1	13	25	
Leucine	$(\text{CH}_3)_2\text{CH}\cdot\text{CH}_2\cdot\text{CH}(\text{NH}_2)\cdot\text{COOH}$	131.2	8	25	
Guanidinoacetic Acid	$\text{HN}\cdot\text{C}\begin{matrix} \nearrow \text{NH}_2 \\ \searrow \text{NH}\cdot\text{CH}_2\cdot\text{COOH} \\ \downarrow \text{CH}_3 \end{matrix}$	117.1	9	25	
Isoleucine	$\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}\cdot\text{CH}(\text{NH}_2)\cdot\text{COOH}$	131.2	4	22	
Urobilinogen			0	17	
Ethanolamine	$\text{NH}_2\cdot\text{CH}_2\cdot\text{CH}_2\text{OH}$	61.1	3	15	∞
Guanidine	$(\text{H}_2\text{N})_2\text{C}\cdot\text{NH}$	59.1	7	13	V.S.
Methionine Sulfoxide			0	13	
Dehydroascorbic Acid	$\text{C}_6\text{H}_6\text{O}_6$	174.1	3	13	
Other Organics				285	

Table II
AN ANALOG REPRESENTING THE COMPOSITION OF TYPICAL HUMAN URINE

ITEM	FORMULA	FORMULA WEIGHT	AMOUNT mg/l
INORGANIC SALTS			14,157
Sodium Chloride	NaCl	58.4	8,001
Potassium Chloride	KCl	74.6	1,641
Potassium Sulfate	K ₂ SO ₄	174.3	2,632
Magnesium Sulfate	MgSO ₄	120.4	783
Magnesium Carbonate	MgCO ₃	84.3	143
Potassium Bicarbonate	KHCO ₃	100.1	661
Potassium Phosphate	K ₃ PO ₄	212.3	234
Calcium Phosphate	Ca ₃ (PO ₄) ₂	310.2	62
UREA			13,400
	H ₂ NCONH ₂	60.1	
ORGANIC COMPOUNDS			5,369
Creatinine	C ₄ H ₇ N ₃ O	113.1	1,504
Uropepsin (as Tyrosine)	HO·C ₆ H ₄ ·C ₂ H ₃ (NH ₂)·CO ₂ H	181.2	381
Creatine	HN·C(NH ₂)N(CH ₃)·CH ₂ ·CO ₂ H·H ₂ O	149.2	373
Glycine	NH ₂ ·CH ₂ ·CO ₂ H	75.1	315
Phenol	C ₆ H ₅ ·OH	94.1	292
Histidine	C ₃ H ₃ N ₂ ·CH ₂ ·CH·(NH ₂)·CO ₂ H	155.2	233
Androsterone	C ₁₉ H ₃₀ O ₂	290.5	174
1-Methylhistidine	C ₃ H ₃ N ₂ CH ₂ CH(NH·CH ₃)·COOH	169.2	173
Imidazole	C ₃ H ₄ N ₂	68.1	143
Glucose	C ₆ H ₇ O ₆ (COCH ₃) ₅	390.4	156
Taurine	NH ₂ ·CH ₂ ·CH ₂ ·SO ₃ H	125.2	138
Cystine	[HO ₂ C·CH(NH ₂)·CH ₂ S·] ₂	240.3	96
Citrulline	NH ₂ CONH(CH ₂) ₃ ·CH·(NH ₂)·CO ₂ H	175.2	88
Aminoisobutyric acid	H ₂ N·CH ₂ CH ₃ > CH·COOH	103.1	84
Threonine	C ₄ H ₉ O ₃ N	119.1	83
Lysine	(NH ₂) ₂ C ₅ H ₉ ·CO ₂ H	146.2	73
Incloxysulfuric acid	C ₈ H ₇ ON·H ₂ SO ₄	231.2	77
m-Hydroxyhippuric acid	C ₄ H ₄ COHC(CONH·CH ₂ COOH)	195.2	70
p-Hydroxyphenyl – hydroacrylic acid			70
Inositol	C ₆ H ₁₂ O ₆	180.2	70
Urobilin	C ₃₃ H ₄₀ O ₆ N ₄	588.7	63
Tyrosine	HO·C ₆ H ₄ ·C ₂ H ₃ (NH ₂)·CO ₂ H	181.2	54
Asparagine	HO ₂ C·CH(NH ₂)·CH ₂ ·CONH ₂	132.1	53
Organics less than 50 mg/l			606
ORGANIC AMMONIUM SALTS			4,131
Ammonium:			
Hippurate	NH ₄ C ₆ H ₅ CO·NHCH ₂ ·CO ₂	196.2	1,250
Citrate	(NH ₄) ₂ HC ₆ H ₅ O ₇	226.2	756
Glucuronate	NH ₄ C ₆ H ₉ O ₇	211.1	663
Urate	NH ₄ C ₅ H ₃ O ₃ N ₄	185.1	518
Lactate	(NH ₄) ₂ C ₃ H ₅ O ₃	127.1	394
L-Glutamate	NH ₄ HO ₂ C·CHNH ₂ ·(CH ₂) ₂ ·CO ₂	164.1	246
Asparate	NH ₄ C ₄ H ₆ O ₄ N	150.1	135
Formate	NH ₄ HCO ₂	63.1	88
Pyruvate	NH ₄ CH ₃ ·CO·CO ₂	88.1	44
Oxalate	(NH ₄) ₂ C ₂ O ₄	124.0	37
Total Solutes			37,057

Table III
SUMMARY OF C, N, O, H AND ORGANICS IN TYPICAL HUMAN URINE

Item	Amount mg/l	C (12.0) mg/l	N (14.0) mg/l	O (16.0) mg/l	H (1.0) mg/l	S (32.1) (Organic) mg/l
Inorganic Salts	14,157	100	0	1,877	7	0
Urea	13,400	2,680	6,253	3,573	893	0
Organic Compounds	5,369	2,466	1,211	1,231	347	134
Organic Ammonium Salts	4,131	1,630	659	1,576	266	0
TOTAL	37,057	6,876	8,123	8,257	1,513	134

Table IV
SIGNIFICANT MEASUREMENTS THAT BROADLY CATEGORIZE HUMAN URINE

Batch No.	TDS g/Kg	n _i	pH	K mmho cm	CO ₂ D g/l	COD g/l	TKN g/l	N By Gas Analysis g/l	TOC g/l	C By Gas Analysis g/l
1.	36.5	1.3386	6.7	17.6	22.6	7.01	7.21	—	6.74	—
2	36.0	1.3383	6.3	19.5	22.2	7.27	4.76	—	6.74	—
3	33.4	1.3381	6.2	19.6	19.9	6.30	6.50	—	6.05	—
4	30.8	1.3381	6.5	21.3	20.5	6.27	6.33	—	6.51	—
5	29.1	1.3384	6.6	22.0	21.0	6.37	6.46	—	6.51	—
6	30.5	1.3377	6.5	19.6	21.8	7.40	6.51	—	5.81	—
7	37.1	1.3387	6.3	19.5	22.1	10.6	7.90	7.39	3.80	4.74
8	30.4	1.3381	6.2	15.9	20.2	10.5	7.54	7.65	—	6.65
9	24.8	1.3376	6.3	16.4	18.4	6.50	6.05	6.51	4.10	4.16
10	26.4	1.3377	6.4	17.0	17.4	8.90	6.24	6.54	3.87	4.46
11	37.1	1.3393	6.5	20.0	24.0	10.3	7.81	7.50	5.00	4.88
12	35.4	1.3383	6.3	18.5	17.7	7.80	6.42	—	4.25	—
13	26.0	1.3375	8.1	17.9	18.4	5.81	5.58	—	3.63	—
14	34.6	1.3384	6.3	19.0	21.8	7.83	—	7.18	4.50	6.54
15	28.1	1.3379	8.3	21.1	—	6.05	—	7.08	3.90	6.05
16	25.7	1.3371	—	—	—	5.57	—	5.51	3.62	4.84

Table V
AN ANALOG REPRESENTING THE SALTS REMAINING AFTER ELECTROLYTIC
PRETREATMENT OF TYPICAL HUMAN URINE

Item	Formula	Formula Weight	Amount mg/l
Sodium Chloride	NaCl	58.4	1,542
Sodium Chlorate	NaClO ₃	106.5	5,314
Sodium Perchlorate	NaClO ₄	122.5	7,436
Potassium Perchlorate	KClO ₄	138.6	776
Potassium Sulfate	K ₂ SO ₄	174.3	4,497
Potassium Nitrate	KNO ₃	101.1	162
Magnesium Chlorate	Mg(ClO ₃) ₂ · 6 H ₂ O	299.3	2,454
Potassium Phosphate	K ₃ PO ₄	212.3	234
Calcium Phosphate	Ca ₃ (PO ₄) ₂	310.2	62
			22,477

Table VI
PHYSICAL PROPERTIES OF URINE CONCENTRATES

LEGEND:

x , Solute weight fraction, g of solutes per g of urine	γ , Surface tension at 70° F, dyne cm^{-1}
ρ , Density at 70° F, g of urine per ml of urine	μ , Dynamic viscosity at 70° F, centipoise
n_D , Refractive index at 70° F relative to air for sodium yellow light	pH, Hydrogen ion concentration at 70° F, \log_{10} of the reciprocal of the molar concentration of hydrogen ions
k , Specific conductivity at 70° F, $\mu\text{mho}\text{-cm}^{-1}$	Ω , liter

Unsmoothed Data

Symbol	Batch No.	Pretreatment	x	n _D	K mmho-cm ⁻¹	pH	ρ g/ml	γ dyne-cm ⁻¹	μ Centipoise	C _p BTU/Lb x °F	M 100° F	W _p W _{SO}	y	$\frac{1}{\rho} \frac{n_D^2 - 1}{n_D^2 + 2}$	ΔT at 120° F Deg. F
Δ	1	H ₂ SO ₄ = 2.57 g/l	0.04174	---	24.0	2.3	1.012	---	0.957	---	---	0	0	---	---
		CrO ₃ = 0.63 g/l	0.1128	1.3493	55.2	2.3	1.046	57.0	1.06	---	64.4	0.0073	0.693	0.2053	1.3
		H ₂ O = 2.56 g/l	0.2247	1.3662	92.0	2.2	1.105	50.4	1.11	---	69.0	0.0090	0.852	0.2028	2.9
		Batch Size = 19l	0.2298	1.3670	93.0	2.2	1.106	50.0	1.37	---	72.1	---	---	0.2030	3.1
			0.3193	1.3820	108.0	2.4	1.150	47.4	1.86	---	62.7	0.0218	0.922	0.2024	4.7
			0.3747	1.3920	114.0	2.8	1.180	45.9	1.95	---	65.6	---	---	0.2018	6.0
			0.4626	1.4072	106.0	2.4	1.232	43.1	4.32	---	64.9	0.0263	0.953	0.2000	8.2
			0.7032	1.4574	48.0	2.6	1.334	44.0	12.1	---	65.2	0.0938	0.979	0.2043	18.5
			0.7548	1.4696	28.0	2.5	1.352	43.5	20.4	---	67.6	0.2022	0.988	0.2062	23.0
			0.8564	1.4932	7.8	3.8	1.382	---	---	---	---	0.2737	0.996	0.2103	---
▲	2	H ₂ SO ₄ = 2.57 g/l	0.3550	---	21.3	2.0	1.010	---	---	---	---	0	0	---	---
		CrO ₂ = 0.63 g/l	0.3047	1.3818	103.0	---	1.147	48.7	1.67	---	64.3	0	0.916	0.2029	4.4
		H ₂ O = 2.56 g/l	0.3750	1.3891	105.0	---	1.169	45.2	2.21	---	66.0	0.0146	0.939	0.2024	5.7
		Batch Size = 19l	0.5674	1.4263	86.0	1.9	1.270	42.9	4.69	---	63.3	0.0567	0.973	0.2019	11.8
			0.7218	1.4502	47.0	2.0	1.313	44.4	13.2	---	65.9	0.1605	0.986	0.2048	19.0
			0.8454	1.4886	10.4	2.5	1.381	46.1	88.6	---	74.3	0.4000	0.995	0.2088	25.6
			0.8660	1.4960	6.0	3.1	1.404	47.8	---	---	---	0.5302	0.997	0.2080	---
○	3	H ₂ SO ₄ = 2.26 g/l	0.04342	---	22.9	2.7	1.015	---	---	---	---	0	0	---	---
		CrO ₃ = 0.56 g/l	0.04406	1.3396	23.7	2.4	1.015	68.0	0.951	---	56.3	---	---	0.2061	---
		CuSO ₄ = 0.18 g/l	0.1591	1.3568	68.5	2.4	1.073	58.8	1.17	---	---	0.00735	0.749	0.2040	1.9
		H ₂ O = 2.68 g/l	0.1610	1.3562	68.0	2.4	1.071	---	---	---	76.0	---	---	0.2041	2.2
		Batch Size = 19l	0.3569	1.3896	107.0	2.3	1.173	46.9	---	---	55.9	---	---	0.2019	6.0
			0.4729	1.4070	104.0	2.7	1.226	44.1	---	---	61.1	0.0281	0.950	0.2008	8.5
			0.6677	1.4396	66.0	2.8	1.309	43.7	---	---	62.4	0.1097	0.979	0.2011	16.1
			0.6728	1.4543	46.8	3.3	1.327	44.3	---	---	51.8	0.2120	0.982	0.2024	18.9
			0.8335	1.4906	7.8	3.5	1.415	45.1	133.5	---	---	0.3491	0.993	0.2045	---
			---	---	---	---	---	---	---	---	---	---	---	---	---
●	4	Mixture of batches 1, 2 and 3 after concentration	0.8250	1.4928	7.4	3.5	1.399	45.3	---	---	---	---	0.2076	---	
			0.8848	1.5078	1.8	3.6	1.439	49.2	---	---	---	---	---	0.2071	---
●	5	Ca(ClO) ₂ · 4H ₂ O = 10 g/l	0.03232	1.3378	18.8	5.4	1.010	70.6	0.950	---	46.3	0.0049	0	0.2063	---
			0.05325	1.3400	29.6	6.9	1.016	68.9	0.965	---	55.6	0.0305	---	0.2063	---
			0.06159	1.3431	36.2	6.8	1.022	---	---	---	55.3	0.0397	---	0.2068	---
			0.08535	1.3458	49.4	7.0	1.035	61.2	1.03	---	59.9	0.0545	---	0.2056	---
			0.1298	1.3525	62.3	7.1	1.050	59.1	1.11	---	62.4	0.581	0.789	0.2062	---
			0.1360	1.3542	69.5	6.7	1.060	55.8	1.13	---	59.5	---	---	0.2052	---
			0.1613	1.3573	79.0	6.9	1.068	52.9	1.17	---	59.7	0.0638	0.837	0.2053	2.1
			0.2251	1.3696	104.0	6.8	1.107	51.2	1.35	---	53.4	0.0759	0.894	0.2041	3.6
			0.3812	1.3948	126.0	6.0	1.177	47.0	2.06	---	52.2	0.0976	0.951	0.2036	7.3
			0.5106	1.4169	122.0	7.2	1.250	40.2	3.73	---	46.2	---	---	0.2011	12.3
			0.5409	1.4238	104.0	6.6	1.251	42.5	4.44	---	46.4	---	---	0.2039	13.9
			0.5728	1.4260	82.0	6.7	1.289	39.8	6.76	---	---	0.3361	0.982	0.1988	---
			0.5880	1.4357	90.0	6.9	1.286	41.0	7.58	---	---	---	---	0.2032	---
			0.6022	1.4350	90.0	6.9	1.282	39.8	6.17	---	41.4	0.4373	0.988	0.2035	17.9

Table VI
PHYSICAL PROPERTIES OF URINE CONCENTRATES (Continued)

Symbol	Batch No.	Pretreatment	x	n _i	K mmho-cm ⁻¹	pH	ρ g/ml	γ dyne-cm ⁻¹	μ Centipoise	C _p BTU/Lb x °F	M at 100° F	W _p W _{AO}	y	$\frac{1}{\rho} \frac{n_i^3 - 1}{n_i^2 + 2}$	ΔT at 120° F Deg. F
□	6	Ca(ClO) ₂ ·4H ₂ O = 10 g/l	0.03407	1.3383	19.5	6.0	1.010	68.4	---	---	42.3	---	0	0.2066	---
			0.03582	1.3385	21.5	6.4	1.013	63.1	1.00	---	---	---	---	0.2061	---
			0.03770	1.3388	22.0	6.6	1.013	63.7	0.952	---	---	0.0058	0.057	0.2063	---
			0.04292	1.3393	24.8	6.8	1.016	50.5	0.989	---	---	0.0087	0.107	0.2059	---
			0.05602	1.3416	31.0	7.8	1.021	49.9	1.00	---	---	0.0195	0.228	0.2062	---
			0.1036	1.3490	62.0	8.7	1.043	45.6	1.14	---	---	0.0250	0.420	0.2058	---
			0.1686	1.3600	84.0	8.1	1.076	45.9	1.36	---	81.8	0.0339	0.705	0.2051	1.4
			0.3516	1.3835	120.0	7.6	1.144	44.2	1.97	---	68.0	---	---	0.2041	4.8
			0.5141	1.4193	118.0	7.6	1.251	40.7	4.62	---	44.3	---	---	0.2018	12.6
			0.6371	1.4418	77.0	6.9	1.293	43.1	11.8	---	49.3	0.1416	0.971	0.2046	18.7
■	7	Ca(ClO) ₂ ·4H ₂ O = 10 g/l	0.03376	1.3389	21.5	6.1	1.014	65.3	---	---	---	---	---	0.2061	---
			0.3856	1.4013	185.0	7.3	1.233	---	---	---	---	0.292	0.961	0.1972	---
			0.394	1.4032	175.0	7.1	1.249	38.6	2.84	---	38.6	---	---	0.1955	9.2
			0.5245	1.4247	112.0	6.7	1.308	34.7	9.13	---	---	---	---	0.1954	---
			0.5206	1.4322	98.0	6.7	1.315	32.3	---	---	---	---	---	0.1973	---
			0.5478	1.4350	85.0	6.5	---	---	---	---	---	---	---	---	---
▼	8	Mixture of batches 4 and 5 after concentration	0.6108	1.4387	86.0	6.8	1.287	39.0	7.53	---	---	---	---	0.2043	---
			0.6456	1.4445	70.0	6.8	1.295	38.4	9.26	---	50.8	0.2582	0.985	0.2053	17.8
			0.6964	1.4575	43.0	6.8	1.314	42.6	18.6	---	---	0.3173	0.990	0.2075	---
			0.7720	1.4730	20.8	6.7	---	---	---	---	---	---	---	---	---
◇	9	Before electrolytic pretreatment. Treated with: Roccal = 0.05 g/l H ₂ O = 0.20 g/l Batch size = 2l	0.3227	1.3380	17.0	6.2	1.011	43.3	0.950	---	---	0	0	0.2061	---
			0.01707	1.3352	13.8	8.7	1.004	71.7	---	---	---	---	---	0.2059	---
			0.09614	1.3468	54.5	8.4	1.048	66.6	1.02	---	---	---	---	0.2036	---
			0.1784	1.3591	88.0	8.6	1.096	59.1	1.23	---	59.8	---	---	0.2009	2.3
			0.2468	1.3700	115.0	9.3	1.138	52.2	1.61	---	---	0.3245	0.963	0.1988	---
			0.3810	1.3924	131.0	9.6	1.227	40.8	2.52	---	---	---	---	0.1942	---
			0.4364	1.4050	115.0	---	1.256	51.9	3.12	---	---	---	---	0.1951	---
◆	10	Electrolytic pretreatment at current density = 200 $\frac{\text{mA}}{\text{cm}^2}$ Batch size = 20l	0.1429	1.3492	96.0	3.2	1.098	72.5	1.22	---	---	0.0605	0.938	0.1955	---
			0.1717	---	---	---	---	---	---	---	53.6	---	---	---	1.8
			0.3141	1.3700	155.0	3.0	1.284	29.4	2.10	---	51.5	0.1358	0.976	0.1762	4.9

Table VI
PHYSICAL PROPERTIES OF URINE CONCENTRATES (Continued)

Smoothed Data From Reference 30

Symbol	Batch No.	Pretreatment	x	n _i	K mmho-cm ⁻¹	pH	ρ g/ml	γ dyne-cm ⁻¹	μ Centipoise	C _p at 73° F BTU/Lb x °F	M at 100° F	$\frac{W_p}{W_{sO}}$	y	$\frac{1}{\rho} \frac{n_i^2 - 1}{n_i^2 + 2}$	ΔT at 120° F Deg. F
⊕	None Littman data (See Ref. 30)		0.05	---	25.0	--	---	52.0	---	0.983	---	---	---	---	---
			0.06	---	---	--	1.024	---	1.05	---	---	---	---	---	---
			0.10	1.3495	49.0	--	1.047	49.0	---	0.930	---	---	---	0.2051	---
			0.16	---	---	--	1.074	---	1.23	---	---	---	---	---	---
			0.17	---	---	--	---	---	---	---	41.4	---	---	---	2.2
			0.20	1.3660	80.0	--	1.097	46.7	---	0.860	---	---	---	0.2042	---
			0.30	1.3830	97.0	--	1.144	45.5	---	0.790	51.4	---	---	0.2039	4.5
			0.31	---	---	--	1.149	---	1.66	---	---	---	---	---	---
			0.40	1.3995	100.0	--	1.193	44.7	2.37	0.720	---	---	---	0.2030	---
			0.43	---	---	--	---	---	---	---	47.8	---	---	---	8.2
			0.50	1.4155	91.5	--	1.244	44.0	---	0.650	---	---	---	0.2015	---
			0.56	---	---	--	---	---	---	---	30.4	---	---	---	14.8
			0.60	1.4325	70.0	--	1.293	43.4	---	---	---	---	---	0.2008	---
			0.66	---	50.0	--	1.310	---	9.96	---	---	---	---	---	---

Table VII
PHYSICAL PROPERTIES OF HUMAN URINE CONCENTRATES
(Nominal Values)

LEGEND:

x	= Solute weight fraction, g of solutes per g of urine
M	= Apparent average molecular weight of solute particles at 100° F
ρ	= Urine density at 70° F, g of urine per ml of urine
C	= Solute concentration at 70° F, g of solutes per ml of urine
C_w	= Water concentration at 70° F, g of water per ml of urine
$\frac{x}{1-x}$	= Solute to water ratio, g of solutes per g of water
O	= Osmolality at 100° F, apparent g-mole of solute particles per 1000 g of water
Or	= Osmolality at 100° F, apparent g-mole of solute particles per liter of urine
$\frac{p}{p^* - p}$	= Ratio of vapor pressure to vapor pressure lowering at 100° F
π	= Osmotic pressure at 100° F, psia
γ	= Surface tension at 70° F, dyne-cm ⁻¹
k	= Specific conductivity at 70° F, mmho-cm ⁻¹
μ_1	= Viscosity of H ₂ SO ₄ + CrO ₃ treated urine at 70° F, centipoise
μ_2	= Viscosity of Ca(ClO) ₂ treated urine at 70° F, centipoise
$\left(\frac{W_p}{W_{so}}\right)_1$	= Weight fraction of precipitated solids of H ₂ SO ₄ + CrO ₃ treated urine, g of precipitate per g of original solute content

$\left(\frac{W_p}{W_{so}}\right)_2$	= Weight fraction of precipitated solids of Ca(ClO) ₂ treated urine, g of precipitate per g of original solute content
$\left(\frac{W_p}{W_{so}}\right)_3$	= Weight fraction of precipitated solids of electrolytically treated urine, g of precipitate per g of original solute content
γ_1	= Weight fraction of extracted water for H ₂ SO ₄ + CrO ₃ treated urine, g of extracted water per g of original water content
γ_2	= Weight fraction of extracted water for Ca(ClO) ₂ treated urine, g of extracted water per g of original water content
γ_3	= Weight fraction of extracted water for electrolytically treated urine, g of extracted water per g of original water content
n_j	= Refractive index at 70° F relative to air for sodium yellow light
H_s	= Differential heat of solution of urine solutes at 90° F, Btu per lb of solutes
L	= Differential heat of vaporization of urine at 90° F, Btu per lb of water evaporated
Lu	= Differential heat of vaporization of urine at 90° F, Btu per lb of urine
C_p	= Specific heat at 73° F, Btu per lb x °F

x	M	ρ	C	C_w	$\frac{x}{1-x}$	O	Or	$\frac{p}{p^* - p}$	π	γ	k	μ_1	μ_2	$\left(\frac{W_p}{W_{so}}\right)_1$	$\left(\frac{W_p}{W_{so}}\right)_2$	$\left(\frac{W_p}{W_{so}}\right)_3$	γ_1	γ_2	γ_3	n_j	H_s	L	Lu	C_p
0.05	52	1.017	0.0509	0.9663	0.0526	1.012	0.9780	54.89	347.8	67.5	28	0.974	0.974	0.002	0.012	0.035				1.340	-23.8	1,042	990	0.963
0.10	63	1.041	0.1041	0.9369	0.1111	1.764	1.652	31.50	602.0	61.7	54	1.06	1.06	0.007	0.038	0.046			0.926	1.348	-16.2	1,041	937	0.930
0.15	70	1.065	0.1597	0.9051	0.1765	2.521	2.282	22.04	854.8	57.2	75	1.17	1.17	0.008	0.044	0.060			0.942	1.356	-12.9	1,041	885	0.895
0.20	72	1.089	0.2177	0.8710	0.2500	3.472	3.024	16.00	1,168	53.6	90	1.31	1.31	0.009	0.052	0.078	0.875		0.954	1.364	-12.1	1,040	832	0.859
0.25	70	1.113	0.2783	0.8345	0.3333	4.762	3.974	11.67	1,584	51.0	101	1.48	1.48	0.011	0.060	0.100	0.895	0.912	0.964	1.372	-12.5	1,039	779	0.822
0.30	67	1.137	0.3409	0.7955	0.4286	6.397	5.089	8.685	2,099	48.8	108	1.71	1.71	0.015	0.068	0.128	0.910	0.932	0.972	1.380	-13.3	1,037	726	0.790
0.35	63	1.160	0.4061	0.7542	0.5385	8.547	6.447	6.500	2,756	47.0	111	2.02	2.02	0.019	0.077	0.165	0.927	0.947	0.980	1.388	-14.5	1,035	673	0.755
0.40	60	1.184	0.4737	0.7105	0.6667	11.11	7.895	5.000	3,512	45.2	113	2.45	2.45	0.021	0.083	0.230	0.941	0.959		1.396	-15.3	1,033	620	0.720
0.45	58	1.208	0.5437	0.6645	0.8182	14.11	9.373	3.938	4,359	43.7	112	3.07	3.07	0.023	0.100		0.953	0.968		1.404	-15.7	1,030	567	0.783
0.50	56	1.232	0.6160	0.6160	1.000	17.86	11.00	3.111	5,369	42.8	107	4.03	4.03	0.029	0.128		0.962	0.975		1.412	-16.0	1,027	514	0.650
0.55	55	1.256	0.6907	0.5651	1.222	22.22	12.56	2.500	6,481	42.4	98	4.79	5.27	0.043	0.170		0.969	0.980		1.423	-15.6	1,024	461	0.616
0.60	55	1.280	0.7678	0.5119	1.500	27.27	13.96	2.037	7,693	42.4	85	5.98	7.45	0.065	0.243		0.974	0.984		1.435	-14.7	1,021	408	0.580
0.65	56	1.304	0.8474	0.4563	1.857	33.16	15.13	1.675	9,016	42.5	67	7.95	11.6	0.092	0.358		0.979	0.988		1.447	-13.2	1,018	356	0.543
0.70	59	1.328	0.9292	0.3983	2.333	39.55	15.75	1.405	10,355	42.7	45	11.6	21.1	0.132	0.515		0.984	0.991		1.459	-11.2	1,017	305	0.505
0.75	64	1.351	1.014	0.3378	3.000	46.87	15.84	1.185	11,785	43.3	29	19.8	48.6	0.187			0.988			1.471	- 8.8	1,016	254	0.472
0.80	71	1.375	1.100	0.2751	4.000	56.34	15.50	0.9861	13,487	44.4	16	44.2		0.266			0.992			1.483	- 6.6	1,017	203	0.440
0.85	78	1.399	1.189	0.2099	5.667	72.65	15.25	0.7647	16,108	46.6	7.5	168		0.419			0.966			1.496	- 4.8	1,016	152	0.402
0.90	86	1.423	1.281	0.1423	9.000	104.7	14.89	0.5309	20,400	50.5	1.8	2,410					0.998			1.508	- 3.2	1,015	101	0.367

Table VIII
VAPOR PRESSURE OF HUMAN URINE CONCENTRATES
NOMINAL VALUES, psia
SOLUTE WEIGHT FRACTION

DEG F	0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90
80.	.5069	.4982	.4918	.4856	.4779	.4681	.4561	.4414	.4250	.4074	.3873	.3663	.3445	.3222	.3008	.2793	.2557	.2233	.1788
81.	.5237	.5147	.5081	.5016	.4937	.4835	.4712	.4559	.4380	.4207	.4004	.3782	.3557	.3326	.3091	.2844	.2584	.2305	.1846
82.	.5410	.5317	.5249	.5182	.5100	.4994	.4866	.4709	.4533	.4345	.4130	.3905	.3672	.3433	.3205	.2977	.2725	.2379	.1905
83.	.5588	.5492	.5421	.5352	.5267	.5158	.5026	.4862	.4682	.4486	.4264	.4031	.3791	.3544	.3308	.3072	.2812	.2455	.1966
84.	.5771	.5671	.5598	.5527	.5439	.5326	.5189	.5020	.4833	.4631	.4401	.4160	.3912	.3657	.3414	.3170	.2902	.2534	.2029
85.	.5959	.5856	.5780	.5706	.5616	.5499	.5358	.5183	.4989	.4780	.4562	.4324	.4077	.3823	.3572	.3321	.2994	.2614	.2093
86.	.6152	.6045	.5967	.5891	.5796	.5676	.5530	.5349	.5149	.4933	.4707	.4465	.4215	.3959	.3704	.3451	.3089	.2697	.2159
87.	.6351	.6240	.6160	.6081	.5985	.5859	.5708	.5521	.5314	.5091	.4857	.4616	.4367	.4112	.3859	.3607	.3241	.2848	.2307
88.	.6556	.6442	.6358	.6277	.6177	.6048	.5891	.5698	.5484	.5253	.4990	.4716	.4433	.4142	.3886	.3630	.3261	.2869	.2327
89.	.6766	.6648	.6562	.6477	.6374	.6241	.6079	.5879	.5658	.5419	.5148	.4864	.4572	.4272	.3997	.3720	.3349	.2959	.2419
90.	.6982	.6860	.6771	.6684	.6577	.6439	.6272	.6066	.5837	.5590	.5310	.5016	.4715	.4405	.4111	.3818	.3435	.3051	.2442
91.	.7204	.7078	.6986	.6896	.6786	.6643	.6470	.6257	.6020	.5766	.5476	.5173	.4861	.4542	.4239	.3936	.3563	.3175	.2518
92.	.7432	.7301	.7207	.7113	.7000	.6852	.6674	.6453	.6209	.5946	.5646	.5334	.5012	.4682	.4369	.4057	.3714	.3324	.2655
93.	.7666	.7531	.7433	.7337	.7220	.7067	.6883	.6655	.6402	.6131	.5821	.5498	.5166	.4826	.4482	.4138	.3782	.3381	.2705
94.	.7906	.7766	.7665	.7566	.7445	.7287	.7097	.6862	.6601	.6320	.6001	.5667	.5324	.4973	.4641	.4309	.3944	.3543	.2869
95.	.8153	.8009	.7904	.7802	.7677	.7514	.7318	.7074	.6805	.6515	.6215	.5901	.5572	.5238	.4904	.4572	.4198	.3798	.3125
96.	.8407	.8258	.8150	.8044	.7915	.7747	.7544	.7293	.7015	.6715	.6407	.6084	.5756	.5422	.5089	.4757	.4382	.3982	.3315
97.	.8668	.8514	.8403	.8293	.8160	.7987	.7777	.7518	.7230	.6921	.6603	.6276	.5943	.5605	.5269	.4934	.4559	.4159	.3495
98.	.8935	.8776	.8661	.8548	.8411	.8232	.8015	.7747	.7451	.7131	.6803	.6468	.6128	.5784	.5440	.5096	.4696	.4296	.3635
99.	.9210	.9046	.8927	.8811	.8669	.8484	.8261	.7984	.7677	.7348	.6993	.6643	.6289	.5932	.5576	.5220	.4819	.4419	.3760
100.	.9492	.9322	.9200	.9080	.8934	.8743	.8512	.8226	.7910	.7570	.7213	.6850	.6487	.6124	.5761	.5398	.4997	.4597	.3940
101.	.9781	.9606	.9480	.9350	.9205	.9008	.8770	.8475	.8148	.7797	.7439	.7076	.6713	.6350	.5987	.5624	.5223	.4823	.4168
102.	1.0078	.9897	.9767	.9633	.9483	.9280	.9034	.8730	.8393	.8031	.7664	.7291	.6918	.6545	.6172	.5799	.5398	.4998	.4345
103.	1.0382	1.0195	1.0061	.9929	.9769	.9559	.9305	.8991	.8643	.8270	.7885	.7492	.7099	.6726	.6353	.5980	.5579	.5179	.4528
104.	1.0695	1.0502	1.0364	1.0228	1.0062	.9846	.9584	.9260	.8901	.8516	.8127	.7734	.7341	.6948	.6555	.6162	.5769	.5369	.4720
105.	1.1016	1.0817	1.0674	1.0534	1.0363	1.0140	.9870	.9536	.9165	.8768	.8366	.7963	.7560	.7167	.6774	.6381	.5988	.5588	.4942
106.	1.1345	1.1139	1.0992	1.0848	1.0672	1.0441	1.0163	.9818	.9436	.9026	.8623	.8220	.7817	.7414	.7011	.6608	.6205	.5805	.5162
107.	1.1683	1.1471	1.1319	1.1170	1.0988	1.0751	1.0464	.9998	.9584	.9161	.8748	.8335	.7922	.7509	.7096	.6683	.6270	.5867	.5228
108.	1.2029	1.1810	1.1654	1.1500	1.1313	1.1068	1.0772	.9405	.9008	.8582	.8169	.7756	.7343	.6930	.6517	.6104	.5691	.5288	.4652
109.	1.2384	1.2158	1.1997	1.1839	1.1646	1.1393	1.1087	1.0709	1.0290	.9840	.9399	.8958	.8517	.8076	.7635	.7194	.6753	.6312	.5680
110.	1.2748	1.2515	1.2349	1.2186	1.1987	1.1726	1.1411	1.1021	1.0589	1.0125	.9698	.9261	.8824	.8387	.7950	.7513	.7076	.6639	.6010
111.	1.3121	1.2881	1.2709	1.2541	1.2336	1.2088	1.1743	1.1341	1.0895	1.0417	.9974	.9531	.9088	.8645	.8202	.7759	.7316	.6879	.6254
112.	1.3504	1.3256	1.3080	1.2907	1.2695	1.2418	1.2048	1.1649	1.1210	1.0717	1.0257	.9814	.9371	.8928	.8485	.8042	.7600	.7157	.6536
113.	1.3896	1.3640	1.3458	1.3280	1.3062	1.2777	1.2432	1.2004	1.1581	1.1093	1.0640	.9207	.9167	.8724	.8281	.7838	.7395	.6952	.6335
114.	1.4298	1.4034	1.3847	1.3663	1.3439	1.3145	1.2789	1.2349	1.1861	1.1337	1.0743	1.0126	.9696	.9253	.8810	.8367	.7924	.7481	.6868
115.	1.4709	1.4437	1.4244	1.4055	1.3824	1.3521	1.3155	1.2700	1.2198	1.1658	1.1046	1.0411	.9762	.9103	.8544	.8001	.7558	.7115	.6506
116.	1.5130	1.4850	1.4651	1.4456	1.4218	1.3906	1.3529	1.3061	1.2542	1.1987	1.1356	1.0702	1.0034	.9356	.8722	.8179	.7736	.7293	.6688
117.	1.5563	1.5274	1.5069	1.4869	1.4624	1.4302	1.3913	1.3431	1.2897	1.2325	1.1675	1.1001	1.0314	.9616	.8964	.8421	.7978	.7535	.6934
118.	1.6006	1.5708	1.5497	1.5291	1.5038	1.4707	1.4306	1.3810	1.3260	1.2670	1.2001	1.1307	1.0600	.9882	.9211	.8551	.8008	.7565	.6968
119.	1.6459	1.6152	1.5935	1.5723	1.5462	1.5121	1.4709	1.4197	1.3630	1.3023	1.2334	1.1620	1.0892	1.0153	.9464	.8855	.8312	.7869	.7276
120.	1.6924	1.6608	1.6384	1.6166	1.5898	1.5546	1.5121	1.4594	1.4011	1.3385	1.2676	1.1940	1.1191	1.0432	.9723	.9026	.8483	.7940	.7352
121.	1.7400	1.7074	1.6844	1.6619	1.6343	1.5981	1.5544	1.5001	1.4400	1.3756	1.3025	1.2268	1.1498	1.0716	.9988	.9322	.8789	.8256	.7674
122.	1.7888	1.7552	1.7315	1.7084	1.6800	1.6427	1.5977	1.5417	1.4799	1.4136	1.3384	1.2604	1.1811	1.1008	1.0259	.9523	.8970	.8437	.7858
123.	1.8387	1.8041	1.7797	1.7559	1.7267	1.6883	1.6419	1.5843	1.5206	1.4524	1.3789	1.2998	1.2192	1.1380	1.0569	.9811	.9258	.8725	.8151
124.	1.8897	1.8540	1.8290	1.8045	1.7744	1.7349	1.6871	1.6278	1.5623	1.4920	1.4173	1.3368	1.2559	1.1745	1.0934	1.0125	.9472	.8939	.8371
125.	1.9420	1.9053	1.8795	1.8543	1.8233	1.7827	1.7335	1.6725	1.6049	1.5326	1.4566	1.3657	1.2794	1.1921	1.1091	1.0312	.9694	.9181	.8625
126.	1.9955	1.9577	1.9312	1.9052	1.8734	1.8315	1.7809	1.7181	1.6486	1.5742	1.4898	1.4024	1.3137	1.2239	1.1405	1.0587	.9969	.9466	.8923
127.	2.0503	2.0113	1.9841	1.9574	1.9246	1.8816	1.8295	1.7648	1.6933	1.6167	1.5298	1.4400	1.3488	1.2565	1.1708	1.0868	.9952	.9459	.8928
128.	2.1064	2.0663	2.0382	2.0108	1.9771	1.9328	1.8792	1.8126	1.7390	1.6602	1.5708	1.4784	1.3846	1.2897	1.2018	1.1155	1.0215	.9732	.9211
129.	2.1638	2.1225	2.0936	2.0654	2.0307	1.9852	1.9300	1.8615	1.7857	1.7047	1.6127	1.5177	1.4213	1.3238	1.2334	1.1449	1.0484	.9916	.9403
130.	2.2225	2.1800	2.1503	2.1213	2.0856	2.0387	1.9820	1.9115	1.8335	1.7501	1.6556	1.5578	1.4587	1.3585	1.2658	1.1749	1.0759	.9986	.9525
131.	2.2826	2.2388	2.2083	2.1785	2.1418	2.0936	2.0352	1.9626	1.8824	1.7967	1.6994	1.5989	1.4970	1.3944	1.2988	1.2056	1.1041	.9931	.9485
132.	2.3440	2.2989	2.2676	2.2369	2.1992	2.1496	2.0895	2.0149	1.9324	1.8442	1.7441	1.6408	1.5361	1.4304	1.3326	1.2369	1.1328	.9881	.9449
133.	2.4069	2.3605	2.3283	2.2967	2.2580	2.2069	2.1451	2.0684	1.9835	1.8928	1.7899	1.6837	1.5761	1.4675	1.3671	1.2690	1.1621	.9931	.9512
134.	2.4712	2.4235	2.3903	2.3579	2.3180	2.2656	2.2020	2.1231	2.0358	1.9425	1.8367	1.7275	1.6170	1.5054	1.4024	1.3017	1.1921	1.0339	.9932
135.	2.5370	2.4879	2.4538	2.4205	2.3795	2.3256	2.2602	2.1790	2.0892	1.9933	1.8846	1.7723	1.6587	1.5442	1.4384	1.3352	1.2228	1.0666	.9865
136.	2.6042	2.5537	2.5186	2.4844	2.4423	2.3868	2.3196	2.2361	2.1438	2.0452	1.9334	1.8181	1.7013	1.5837	1.4752	1.3693	1.2541	1.0939	.9874
137.	2.6729	2.6209	2.5849	2.5497	2.5065	2.4494	2.3807	2.2945	2.1996	2.0982	1.9833	1.8647	1.7449	1.6241	1.5127	1.4042	1.2860	1.1217	.9966
138.	2.7432	2.6897	2.6527	2.6166	2.5721	2.5135	2.4424	2.3542	2.2566	2.1524	2.0343	1.9125	1.7893	1.6653	1.5511	1.4398	1.3187	1.1502	.9993
139.	2.8151	2.7601	2.7221	2.6850	2.6392	2.5790	2.5060	2.4152	2.3149	2.2078	2.0864	1.9613	1.8348	1.7075	1.5903	1.4762	1.3520	1.1793	.9925
140.	2.8886	2.8320	2.7930	2.7548	2.7079	2.6459	2.5709	2.4											

TABLE IX
TABLE HEADINGS

x	= solute weight fraction, g of solutes per g of urine
L/L^*	= ratio of heat of vaporization of urine to heat of vaporization of pure water
Lu	= differential heat of vaporization of urine, BTU/lb of urine
Hw	= differential heat of dilution, BTU/lb of water increase
Hs	= differential heat of dilution, BTU/lb of solute increase
L	= differential heat of vaporization of urine, BTU/lb of water evaporated

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES)

x	L/L*	Lu	Hw	Hs	L
.05	.9989	994.0	1.181	-22.436	1046.3
.10	.9984	941.2	1.696	-15.268	1045.8
.15	.9979	888.5	2.161	-12.248	1045.3
.20	.9973	835.7	2.861	-11.444	1044.6
.25	.9962	782.7	3.946	-11.839	1043.6
.30	.9949	729.5	5.383	-12.561	1042.1
.35	.9930	676.1	7.367	-13.681	1040.1
.40	.9908	622.7	9.655	-14.483	1037.8
.45	.9884	569.5	12.130	-14.825	1035.4
.50	.9856	516.2	15.081	-15.081	1032.4
.55	.9828	463.3	18.039	-14.759	1029.5
.60	.9801	410.7	20.824	-13.883	1026.7
.65	.9778	358.5	23.276	-12.533	1024.2
.70	.9764	306.8	24.688	-10.580	1022.8
.75	.9760	255.6	25.181	- 8.394	1022.3
.80	.9760	204.5	25.125	- 6.281	1022.4
.85	.9753	153.2	25.883	- 4.568	1021.6
.90	.9740	102.0	27.215	- 3.024	1020.3

TEMPERATURE OF URINE CONCENTRATE = 82.0

x	L/L*	Lu	Hw	Hs	L
.05	.9988	991.8	1.214	-23.064	1044.0
.10	.9983	939.1	1.744	-15.695	1043.5
.15	.9979	886.5	2.230	-12.639	1043.0
.20	.9972	833.8	2.938	-11.753	1042.3
.25	.9961	780.9	4.052	-12.157	1041.1
.30	.9947	727.8	5.529	-12.901	1039.7
.35	.9927	674.5	7.584	-14.085	1037.6
.40	.9905	621.2	9.937	-14.906	1035.3
.45	.9881	568.0	12.478	-15.251	1032.7
.50	.9852	514.8	15.512	-15.512	1029.7
.55	.9822	462.0	18.562	-15.187	1026.6
.60	.9795	409.5	21.415	-14.277	1023.8
.65	.9771	357.4	23.932	-12.887	1021.3
.70	.9757	306.0	25.353	-10.866	1019.8
.75	.9753	254.8	25.838	- 8.613	1019.4
.80	.9754	203.9	25.743	- 6.436	1019.5
.85	.9747	152.8	26.484	- 4.674	1018.7
.90	.9734	101.7	27.805	- 3.090	1017.4

TEMPERATURE OF URINE CONCENTRATE = 86.0

Table IX

DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9988	989.6	1.254	-23.827	1041.6
.10	.9983	937.0	1.799	-16.189	1041.1
.15	.9978	884.5	2.285	-12.948	1040.6
.20	.9971	831.9	3.018	-12.072	1039.9
.25	.9960	779.1	4.162	-12.485	1038.7
.30	.9945	726.1	5.685	-13.264	1037.2
.35	.9925	672.8	7.793	-14.472	1035.1
.40	.9902	619.6	10.215	-15.323	1032.7
.45	.9877	566.5	12.832	-15.683	1030.1
.50	.9847	513.5	15.963	-15.963	1026.9
.55	.9817	460.7	19.093	-15.622	1023.8
.60	.9789	408.3	22.031	-14.687	1020.9
.65	.9764	356.4	24.597	-13.244	1018.3
.70	.9750	305.1	26.037	-11.159	1016.9
.75	.9746	254.1	26.498	- 8.833	1016.4
.80	.9747	203.3	26.367	- 6.592	1016.5
.85	.9740	152.4	27.099	- 4.782	1015.8
.90	.9728	101.4	28.418	- 3.158	1014.5

TEMPERATURE OF URINE CONCENTRATE = 90.0

x	L/L*	Lu	Hw	Hs	L
.05	.9988	987.4	1.297	-24.639	1039.4
.10	.9982	935.0	1.843	-16.585	1038.9
.15	.9977	882.6	2.358	-13.360	1038.3
.20	.9970	830.1	3.100	-12.401	1037.6
.25	.9959	777.3	4.282	-12.847	1036.4
.30	.9944	724.4	5.839	-13.625	1034.9
.35	.9923	671.2	8.015	-14.884	1032.7
.40	.9899	618.1	10.520	-15.779	1030.2
.45	.9873	565.1	13.220	-16.158	1027.5
.50	.9842	512.1	16.437	-16.437	1024.3
.55	.9811	459.5	19.662	-16.087	1021.0
.60	.9782	407.2	22.671	-15.114	1018.0
.65	.9757	355.4	25.302	-13.624	1015.4
.70	.9743	304.2	26.753	-11.466	1013.9
.75	.9739	253.4	27.193	- 9.064	1013.5
.80	.9740	202.7	27.030	- 6.758	1013.7
.85	.9733	151.9	27.741	- 4.895	1013.0
.90	.9721	101.2	29.056	- 3.229	1011.6

TEMPERATURE OF URINE CONCENTRATE = 94.0

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9987	985.2	1.339	-25.432	1037.1
.10	.9982	932.8	1.906	-17.154	1036.5
.15	.9977	880.6	2.412	-13.670	1036.0
.20	.9969	828.2	3.180	-12.719	1035.2
.25	.9958	775.5	4.389	-13.168	1034.0
.30	.9942	722.7	6.002	-14.005	1032.4
.35	.9921	669.6	8.241	-15.306	1030.2
.40	.9896	616.6	10.803	-16.205	1027.6
.45	.9869	563.6	13.582	-16.600	1024.8
.50	.9837	510.8	16.896	-16.896	1021.5
.55	.9805	458.2	20.210	-16.536	1018.2
.60	.9776	406.0	23.293	-15.529	1015.1
.65	.9750	354.3	25.982	-13.990	1012.4
.70	.9736	303.3	27.448	-11.763	1011.0
.75	.9732	252.6	27.860	- 9.287	1010.5
.80	.9734	202.2	27.649	- 6.912	1010.8
.85	.9727	151.5	28.343	- 5.002	1010.1
.90	.9714	100.9	29.653	- 3.295	1008.7

TEMPERATURE OF URINE CONCENTRATE = 98.0

x	L/L*	Lu	Hw	Hs	L
.05	.9987	983.0	1.386	-26.334	1034.7
.10	.9981	930.7	1.956	-17.602	1034.1
.15	.9976	878.6	2.485	-14.080	1033.6
.20	.9968	826.3	3.276	-13.102	1032.8
.25	.9956	773.7	4.513	-13.540	1031.6
.30	.9940	721.0	6.168	-14.392	1029.9
.35	.9918	668.0	8.471	-15.731	1027.6
.40	.9893	615.0	11.130	-16.695	1025.0
.45	.9865	562.2	13.982	-17.090	1022.1
.50	.9832	509.3	17.403	-17.403	1018.7
.55	.9799	456.9	20.806	-17.023	1015.3
.60	.9769	404.8	23.977	-15.985	1012.1
.65	.9742	353.3	26.720	-14.388	1009.4
.70	.9728	302.4	28.203	-12.087	1007.9
.75	.9724	251.9	28.593	- 9.531	1007.5
.80	.9726	201.6	28.339	- 7.085	1007.8
.85	.9720	151.1	29.013	- 5.120	1007.1
.90	.9707	100.6	30.316	- 3.368	1005.8

TEMPERATURE OF URINE CONCENTRATE = 102.0

Table IX

DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9986	980.8	1.423	-27.033	1032.4
.10	.9981	928.6	2.011	-18.098	1031.8
.15	.9975	876.6	2.551	-14.455	1031.2
.20	.9968	824.4	3.352	-13.408	1030.4
.25	.9955	771.9	4.639	-13.917	1029.2
.30	.9939	719.2	6.329	-14.768	1027.5
.35	.9916	666.3	8.708	-16.172	1025.1
.40	.9889	613.4	11.427	-17.141	1022.4
.45	.9861	560.7	14.366	-17.559	1019.4
.50	.9827	508.0	17.877	-17.877	1015.9
.55	.9793	455.6	21.382	-17.494	1012.4
.60	.9762	403.7	24.623	-16.415	1009.2
.65	.9735	352.2	27.436	-14.773	1006.4
.70	.9720	301.5	28.922	-12.395	1004.9
.75	.9717	251.1	29.284	-9.761	1004.5
.80	.9720	201.0	28.983	-7.246	1004.8
.85	.9713	150.6	29.636	-5.230	1004.2
.90	.9701	100.3	30.926	-3.436	1002.9

TEMPERATURE OF URINE CONCENTRATE = 106.0

x	L/L*	Lu	Hw	Hs	L
.05	.9986	978.6	1.469	-27.909	1030.1
.10	.9980	926.6	2.068	-18.612	1029.5
.15	.9975	874.6	2.617	-14.827	1029.0
.20	.9967	822.5	3.442	-13.769	1028.2
.25	.9954	770.1	4.749	-14.248	1026.9
.30	.9937	717.6	6.513	-15.198	1025.1
.35	.9913	664.7	8.938	-16.600	1022.7
.40	.9886	611.9	11.752	-17.628	1019.8
.45	.9857	559.2	14.791	-18.078	1016.8
.50	.9822	506.6	18.405	-18.405	1013.2
.55	.9787	454.3	22.000	-18.000	1009.6
.60	.9754	402.5	25.330	-16.887	1006.3
.65	.9727	351.2	28.196	-15.182	1003.4
.70	.9712	300.6	29.696	-12.727	1001.9
.75	.9709	250.4	30.035	-10.012	1001.6
.80	.9712	200.4	29.680	-7.420	1001.9
.85	.9706	150.2	30.310	-5.349	1001.3
.90	.9694	100.0	31.592	-3.510	1000.0

TEMPERATURE OF URINE CONCENTRATE = 110.0

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9985	976.3	1.518	-28.839	1027.7
.10	.9979	924.4	2.131	-19.177	1027.1
.15	.9974	872.5	2.689	-15.236	1026.5
.20	.9966	820.5	3.541	-14.165	1025.7
.25	.9952	768.2	4.890	-14.670	1024.3
.30	.9935	715.8	6.686	-15.601	1022.5
.35	.9911	663.0	9.210	-17.105	1020.0
.40	.9882	610.3	12.106	-18.159	1017.1
.45	.9852	557.7	15.222	-18.604	1014.0
.50	.9816	505.1	18.946	-18.946	1010.3
.55	.9780	452.9	22.664	-18.543	1006.5
.60	.9747	401.2	26.084	-17.390	1003.1
.65	.9718	350.1	29.013	-15.622	1000.2
.70	.9703	299.6	30.524	-13.082	998.7
.75	.9700	249.6	30.827	-10.276	998.4
.80	.9704	199.8	30.423	- 7.606	998.8
.85	.9699	149.7	31.029	- 5.476	998.2
.90	.9686	99.7	32.297	- 3.589	996.9

TEMPERATURE OF URINE CONCENTRATE = 114.0

x	L/L*	Lu	Hw	Hs	L
.05	.9985	974.1	1.560	-29.641	1025.3
.10	.9979	922.2	2.187	-19.680	1024.7
.15	.9973	870.5	2.754	-15.697	1024.1
.20	.9965	818.6	3.622	-14.486	1023.3
.25	.9951	766.4	5.013	-15.040	1021.9
.30	.9933	714.0	6.857	-16.000	1020.0
.35	.9908	661.3	9.455	-17.559	1017.4
.40	.9879	608.7	12.430	-18.645	1014.5
.45	.9848	556.2	15.639	-19.115	1011.3
.50	.9810	503.7	19.476	-19.476	1007.4
.55	.9773	451.6	23.275	-19.043	1003.6
.60	.9739	400.0	26.780	-17.853	1000.1
.65	.9710	349.0	29.776	-16.033	997.1
.70	.9695	298.7	31.290	-13.410	995.6
.75	.9693	248.8	31.563	-10.521	995.3
.80	.9697	199.2	31.104	- 7.776	995.8
.85	.9691	149.3	31.686	- 5.592	995.2
.90	.9679	99.4	32.940	- 3.660	994.0

TEMPERATURE OF URINE CONCENTRATE = 118.0

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9984	971.8	1.621	-30.790	1023.0
.10	.9978	920.1	2.252	-20.267	1022.3
.15	.9972	868.5	2.835	-16.066	1021.8
.20	.9964	816.7	3.730	-14.918	1020.9
.25	.9950	764.6	5.151	-15.452	1019.4
.30	.9931	712.3	7.061	-16.475	1017.5
.35	.9905	659.7	9.713	-18.039	1014.9
.40	.9875	607.1	12.786	-19.179	1011.8
.45	.9843	554.7	16.080	-19.654	1008.5
.50	.9805	502.3	20.030	-20.030	1004.6
.55	.9766	450.3	23.948	-19.594	1000.7
.60	.9731	398.8	27.545	-18.363	997.1
.65	.9701	347.9	30.604	-16.479	994.0
.70	.9686	297.7	32.135	-13.772	992.5
.75	.9684	248.1	32.374	-10.791	992.2
.80	.9689	198.6	31.848	-7.962	992.8
.85	.9684	148.8	32.402	-5.718	992.2
.90	.9672	99.1	33.639	-3.738	991.0

TEMPERATURE OF URINE CONCENTRATE = 122.0

x	L/L*	Lu	Hw	Hs	L
.05	.9984	969.6	1.664	-31.610	1020.6
.10	.9977	918.0	2.312	-20.812	1020.0
.15	.9971	866.5	2.915	-16.517	1019.4
.20	.9963	814.8	3.828	-15.312	1018.5
.25	.9948	762.8	5.283	-15.848	1017.0
.30	.9929	710.5	7.237	-16.887	1015.1
.35	.9902	658.0	9.993	-18.559	1012.3
.40	.9871	605.5	13.151	-19.727	1009.1
.45	.9838	553.2	16.560	-20.240	1005.7
.50	.9798	500.8	20.618	-20.618	1001.7
.55	.9759	448.9	24.640	-20.160	997.7
.60	.9723	397.6	28.323	-18.882	994.0
.65	.9692	346.8	31.454	-16.937	990.8
.70	.9677	296.8	32.990	-14.139	989.3
.75	.9675	247.3	33.174	-11.058	989.1
.80	.9681	197.9	32.609	-8.152	989.7
.85	.9676	148.4	33.123	-5.845	989.2
.90	.9664	98.8	34.349	-3.817	988.0

TEMPERATURE OF URINE CONCENTRATE = 126.0

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9983	967.4	1.722	-32.727	1018.3
.10	.9977	915.9	2.386	-21.477	1017.6
.15	.9971	864.5	2.989	-16.936	1017.0
.20	.9962	812.9	3.921	-15.684	1016.1
.25	.9947	760.9	5.434	-16.302	1014.6
.30	.9927	708.8	7.440	-17.361	1012.6
.35	.9899	656.3	10.269	-19.070	1009.7
.40	.9867	603.9	13.524	-20.285	1006.5
.45	.9833	551.6	17.022	-20.805	1003.0
.50	.9792	499.4	21.207	-21.207	998.8
.55	.9751	447.6	25.349	-20.740	994.7
.60	.9714	396.3	29.129	-19.419	990.9
.65	.9683	345.7	32.323	-17.405	987.7
.70	.9668	295.8	33.865	-14.513	986.1
.75	.9666	246.5	34.021	-11.340	986.0
.80	.9673	197.3	33.368	- 8.342	986.6
.85	.9668	147.9	33.863	- 5.976	986.1
.90	.9656	98.5	35.065	- 3.896	984.9

TEMPERATURE OF URINE CONCENTRATE = 130.0

x	L/L*	Lu	Hw	Hs	L
.05	.9982	965.0	1.781	-33.840	1015.8
.10	.9976	913.6	2.454	-22.086	1015.1
.15	.9970	862.4	3.069	-17.393	1014.5
.20	.9960	810.9	4.028	-16.113	1013.6
.25	.9945	759.0	5.572	-16.717	1012.0
.30	.9925	707.0	7.650	-17.850	1009.9
.35	.9896	654.6	10.555	-19.603	1007.0
.40	.9863	602.2	13.905	-20.857	1003.7
.45	.9828	550.1	17.506	-21.396	1000.1
.50	.9786	497.9	21.818	-21.818	995.8
.55	.9744	446.2	26.066	-21.327	991.5
.60	.9706	395.1	29.946	-19.964	987.7
.65	.9674	344.5	33.207	-17.981	984.4
.70	.9659	294.0	34.743	-14.890	982.9
.75	.9657	245.7	34.856	-11.619	982.7
.80	.9664	196.7	34.156	- 8.539	983.4
.85	.9660	147.4	34.605	- 6.107	983.0
.90	.9648	98.2	35.784	- 3.976	981.8

TEMPERATURE OF URINE CONCENTRATE = 134.0

Table IX
DIFFERENTIAL HEATS OF VAPORIZATION, SOLUTION,
AND DILUTION (NOMINAL VALUES) (Continued)

x	L/L*	Lu	Hw	Hs	L
.05	.9982	962.8	1.833	-34.823	1013.5
.10	.9975	911.5	2.518	-22.659	1012.8
.15	.9969	860.3	3.154	-17.873	1012.1
.20	.9959	808.9	4.136	-16.543	1011.2
.25	.9944	757.2	5.724	-17.171	1009.6
.30	.9923	705.2	7.850	-18.316	1007.4
.35	.9893	652.9	10.849	-20.148	1004.5
.40	.9859	600.6	14.304	-21.456	1001.0
.45	.9823	548.5	18.010	-22.012	997.3
.50	.9779	496.4	22.453	-22.453	992.8
.55	.9736	444.8	26.825	-21.948	988.5
.60	.9697	393.8	30.806	-20.537	984.5
.65	.9664	343.4	34.129	-18.377	981.2
.70	.9649	293.9	35.677	-15.290	979.6
.75	.9648	244.9	35.740	-11.913	979.6
.80	.9656	196.1	34.954	- 8.739	980.3
.85	.9652	147.0	35.375	- 6.243	979.9
.90	.9640	97.9	36.537	- 4.060	978.8

TEMPERATURE OF URINE CONCENTRATE = 138.0

x	L/L*	Lu	Hw	Hs	L
.05	.9981	960.4	1.901	-36.122	1011.0
.10	.9974	909.3	2.599	-23.392	1010.3
.15	.9968	858.2	3.237	-18.342	1009.7
.20	.9958	806.9	4.246	-16.984	1008.7
.25	.9942	755.3	5.879	-17.636	1007.0
.30	.9920	703.4	8.056	-18.798	1004.8
.35	.9890	651.1	11.147	-20.702	1001.8
.40	.9855	598.9	14.708	-22.062	998.2
.45	.9817	546.9	18.530	-22.648	994.4
.50	.9772	494.9	23.099	-23.099	989.8
.55	.9728	443.4	27.597	-22.579	985.3
.60	.9687	392.5	31.670	-21.113	981.2
.65	.9654	342.2	35.082	-18.890	977.8
.70	.9638	292.9	36.623	-15.696	976.3
.75	.9638	244.1	36.633	-12.211	976.3
.80	.9647	195.4	35.775	- 8.944	977.1
.85	.9643	146.5	36.155	- 6.380	976.7
.90	.9632	97.6	37.294	- 4.144	975.6

TEMPERATURE OF URINE CONCENTRATE = 142.0

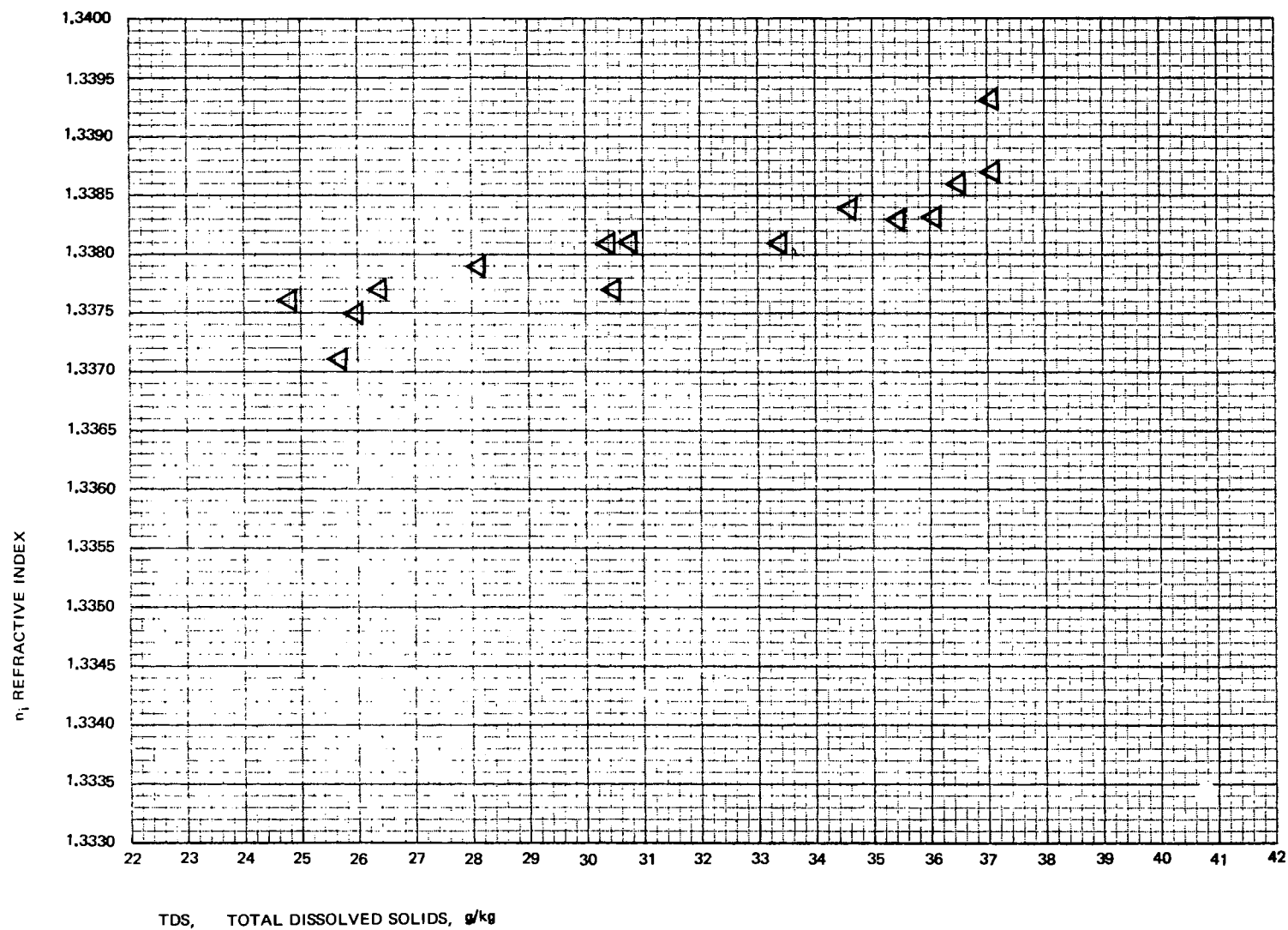


Figure 1. Refractive Index of Human Urine

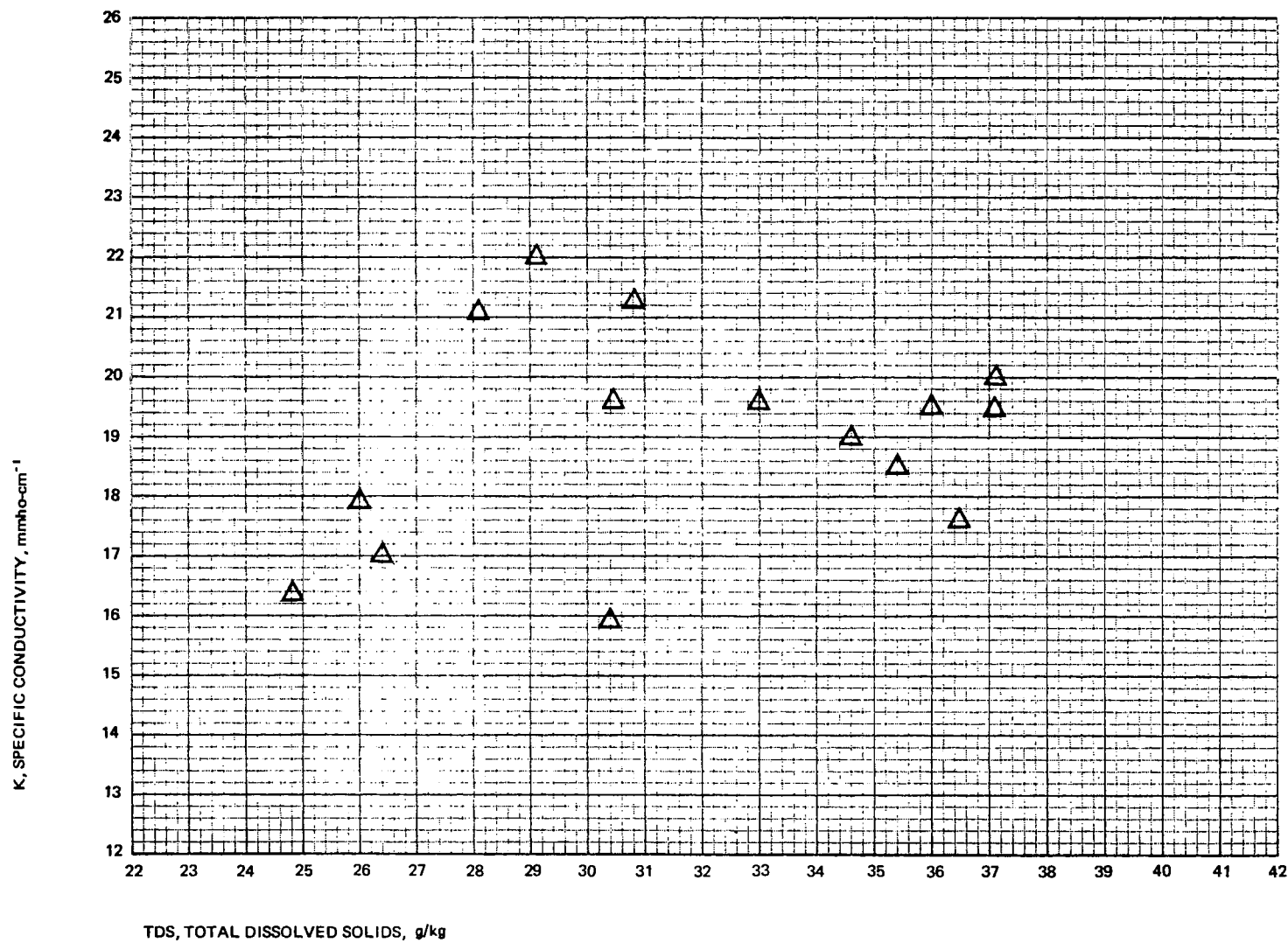


Figure 2. Specific Conductivity of Human Urine

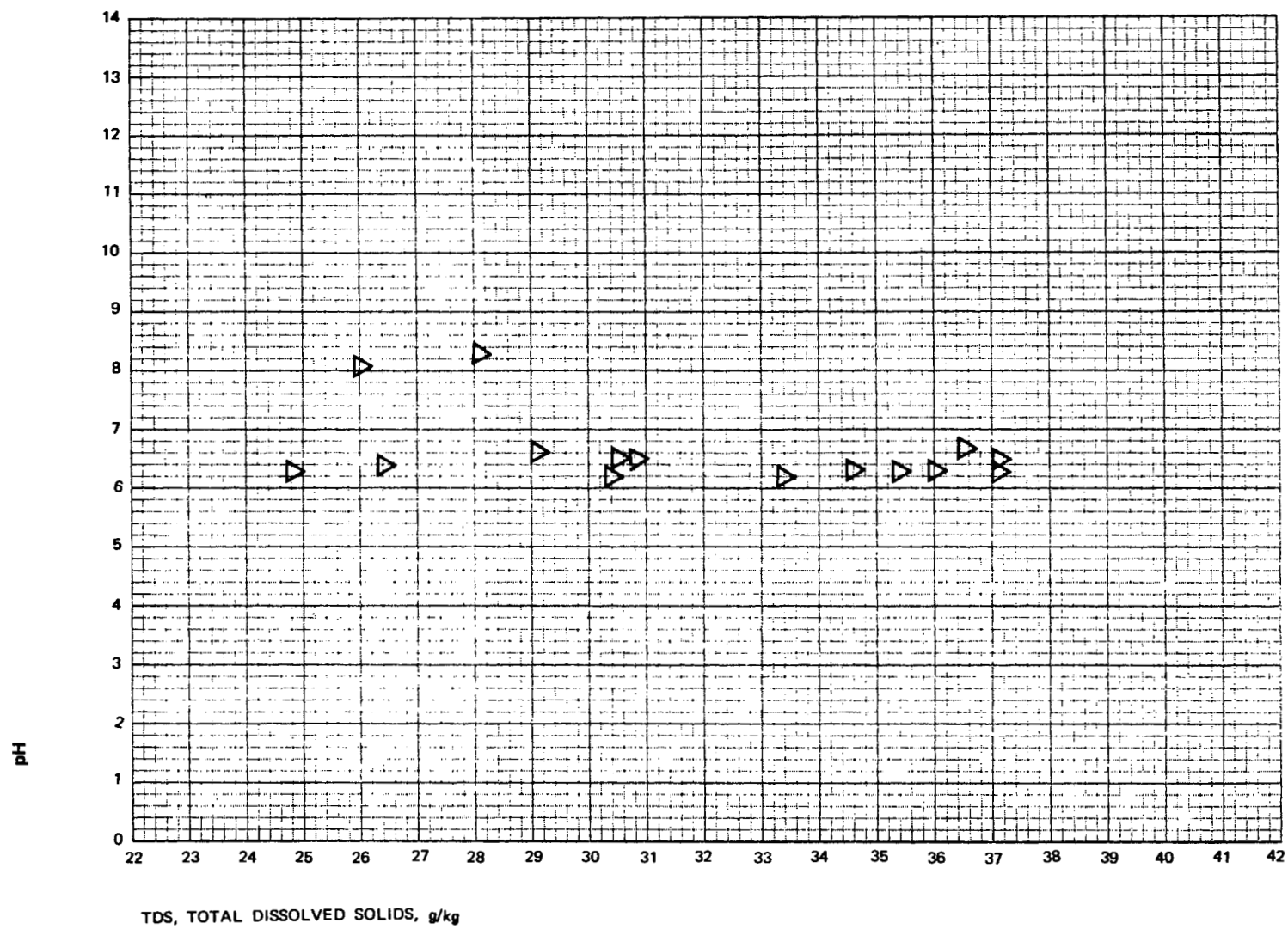


Figure 3. pH of Human Urine

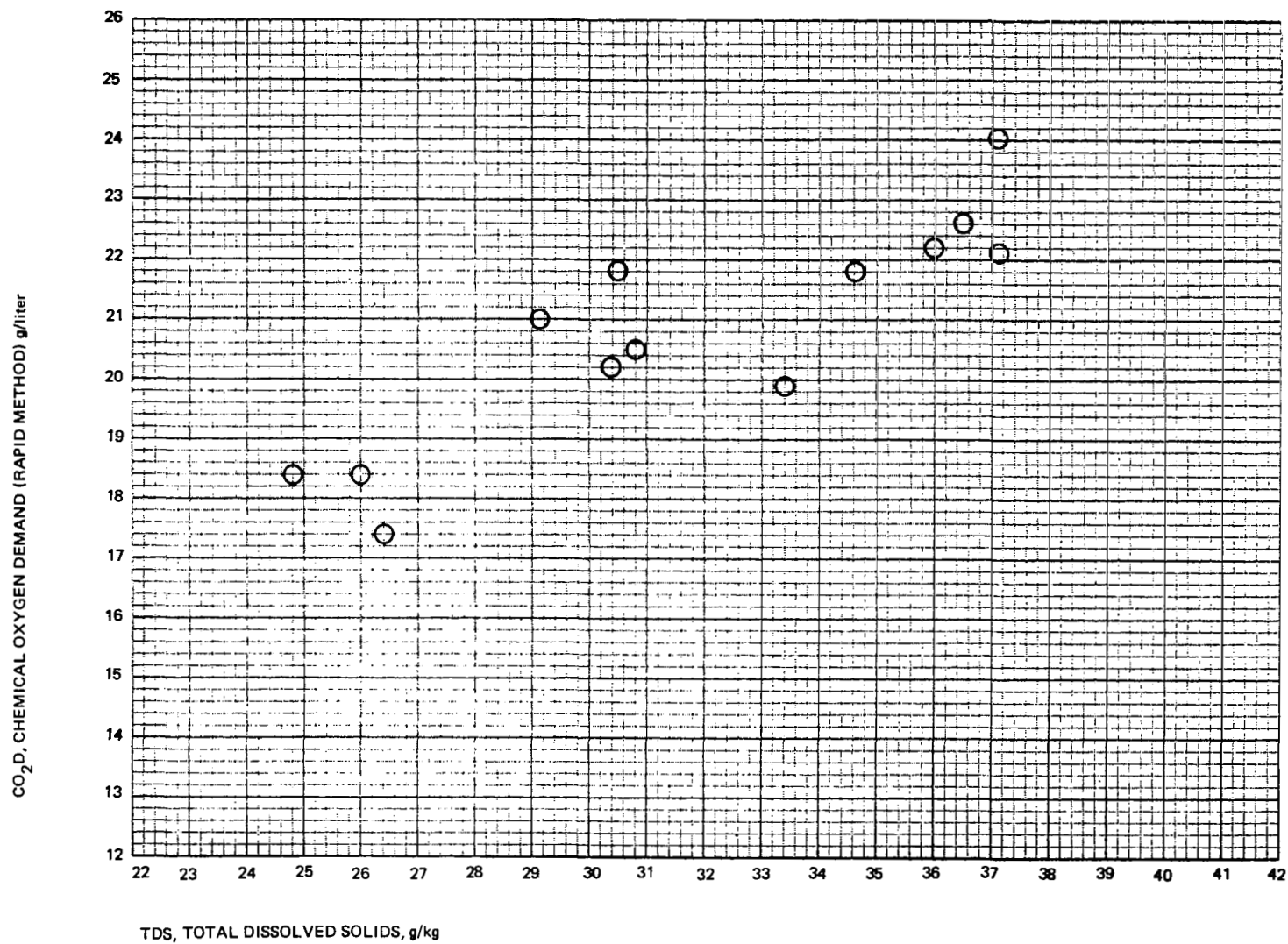


Figure 4. Chemical Oxygen Demand of Human Urine (Rapid Method)

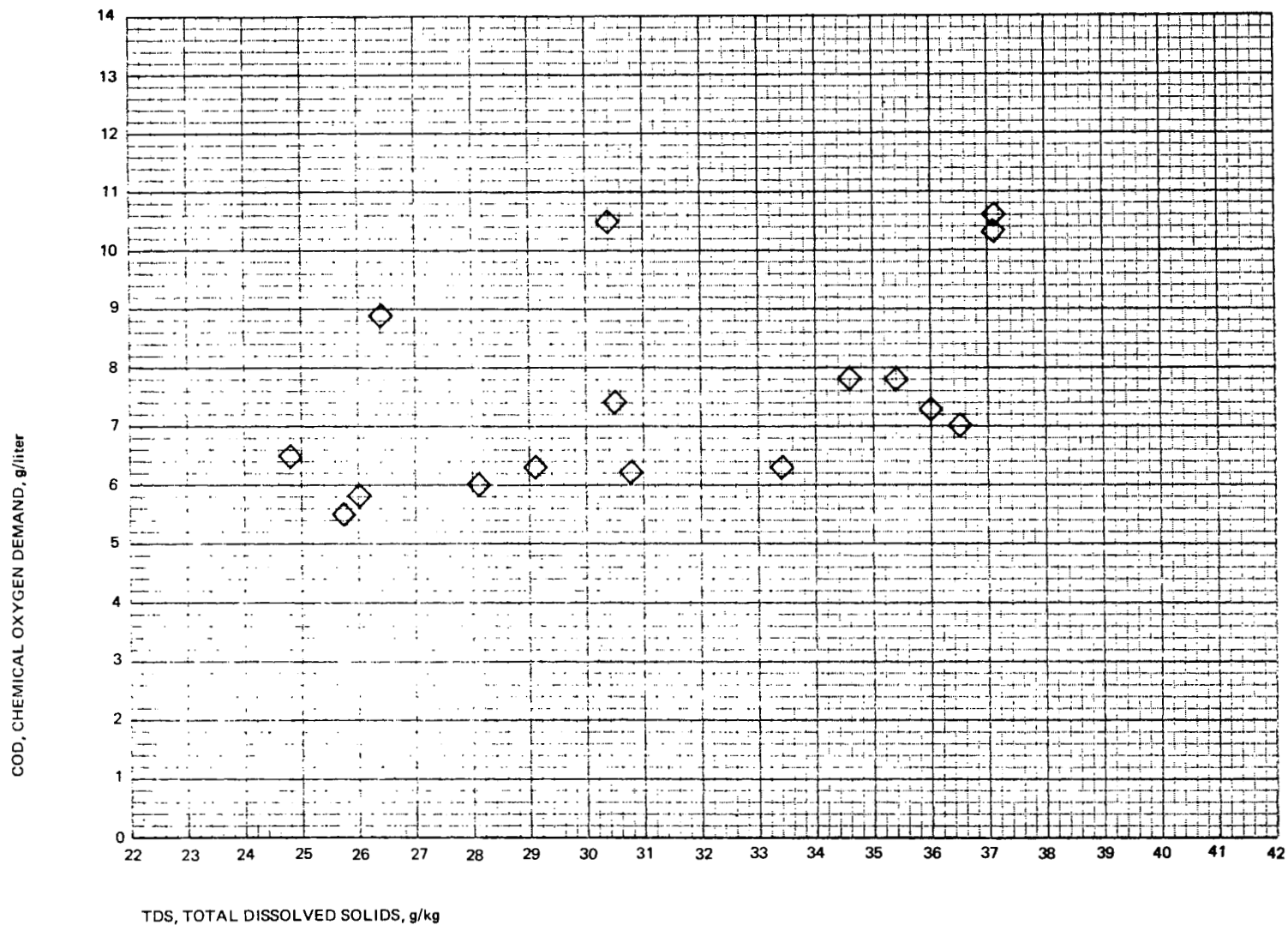


Figure 5. Chemical Oxygen Demand of Human Urine

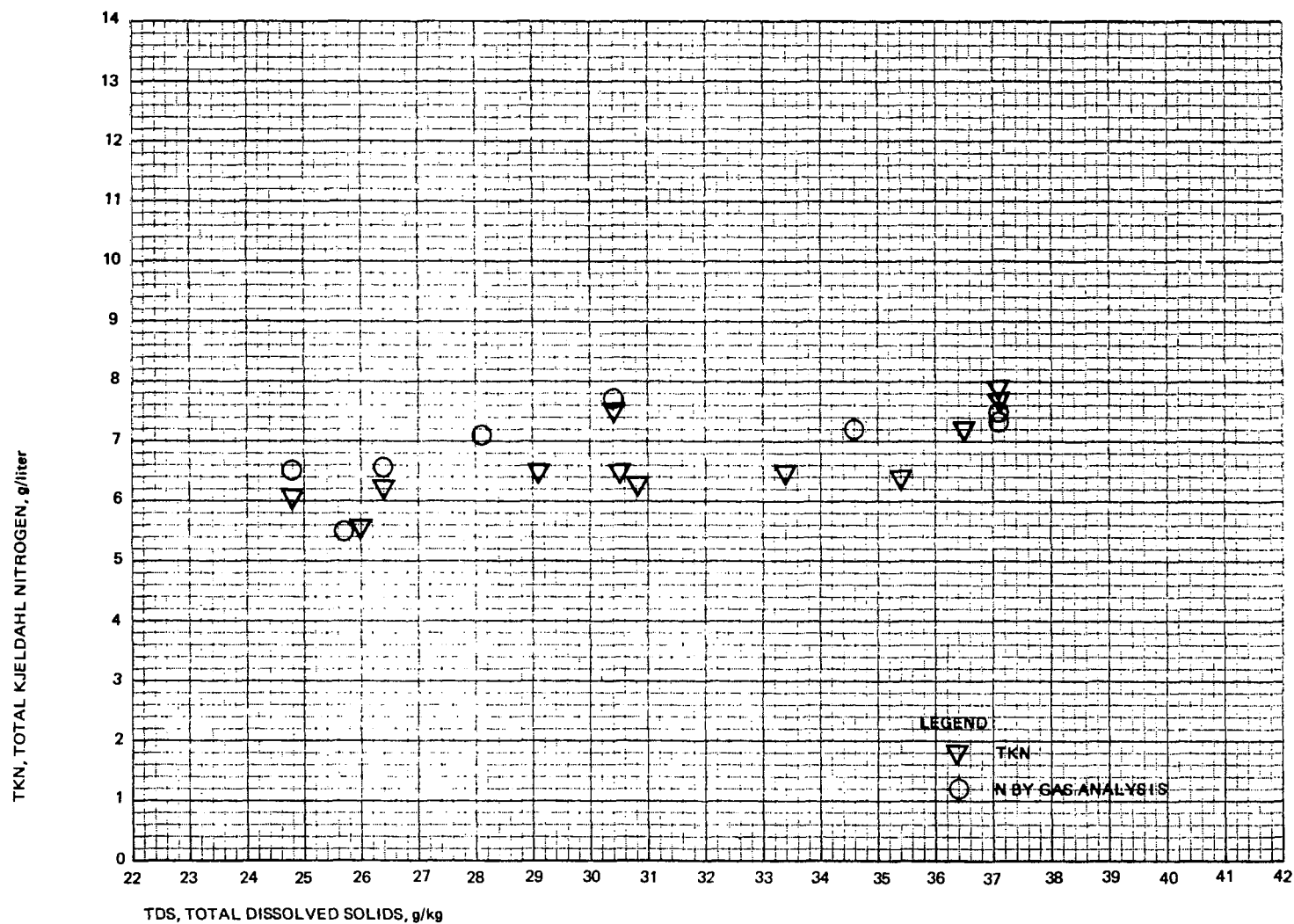


Figure 6. Total Kjeldahl Nitrogen of Human Urine

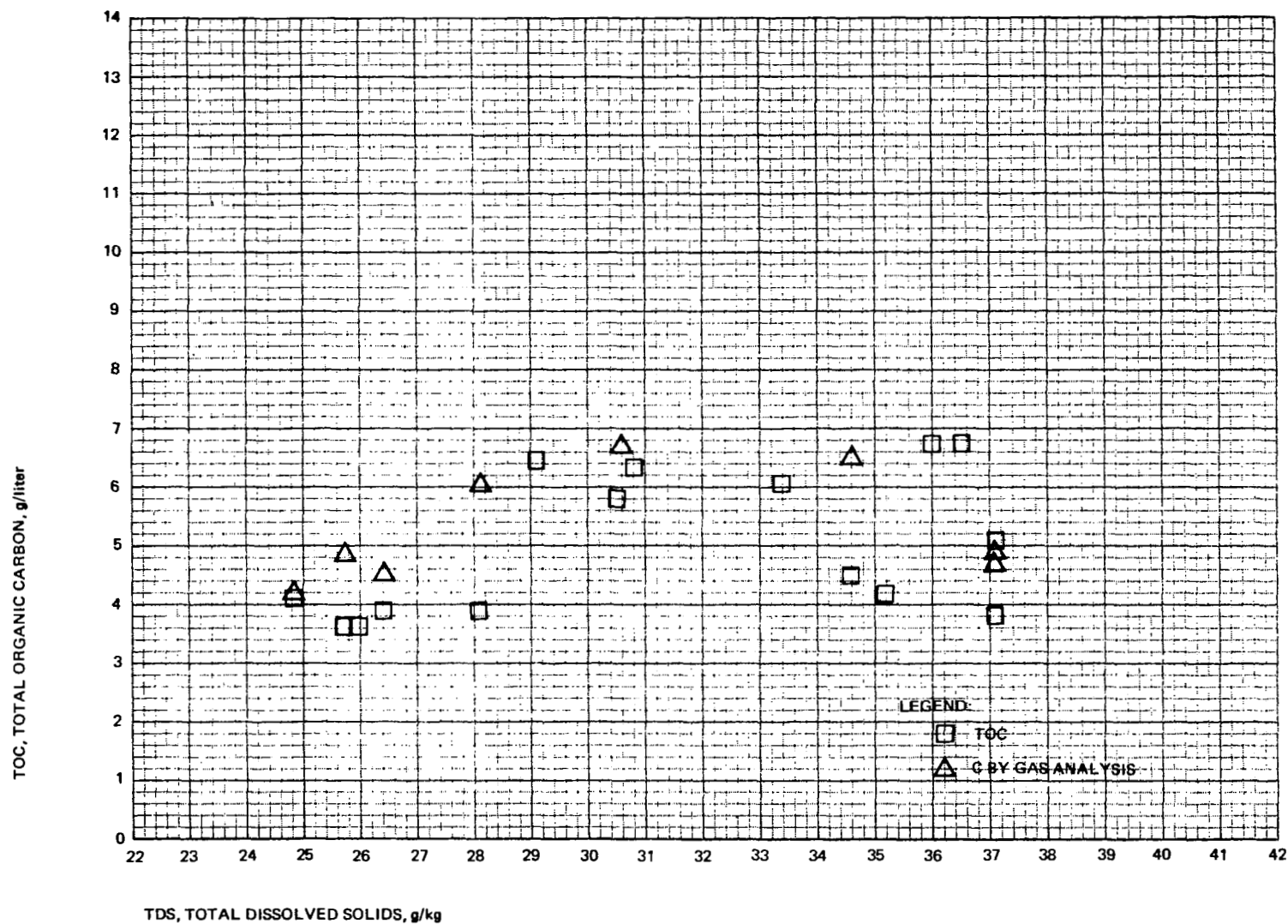


Figure 7. Total Organic Carbon of Human Urine

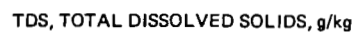


Figure 8. Ratio of Nitrogen to Carbon in Human Urine

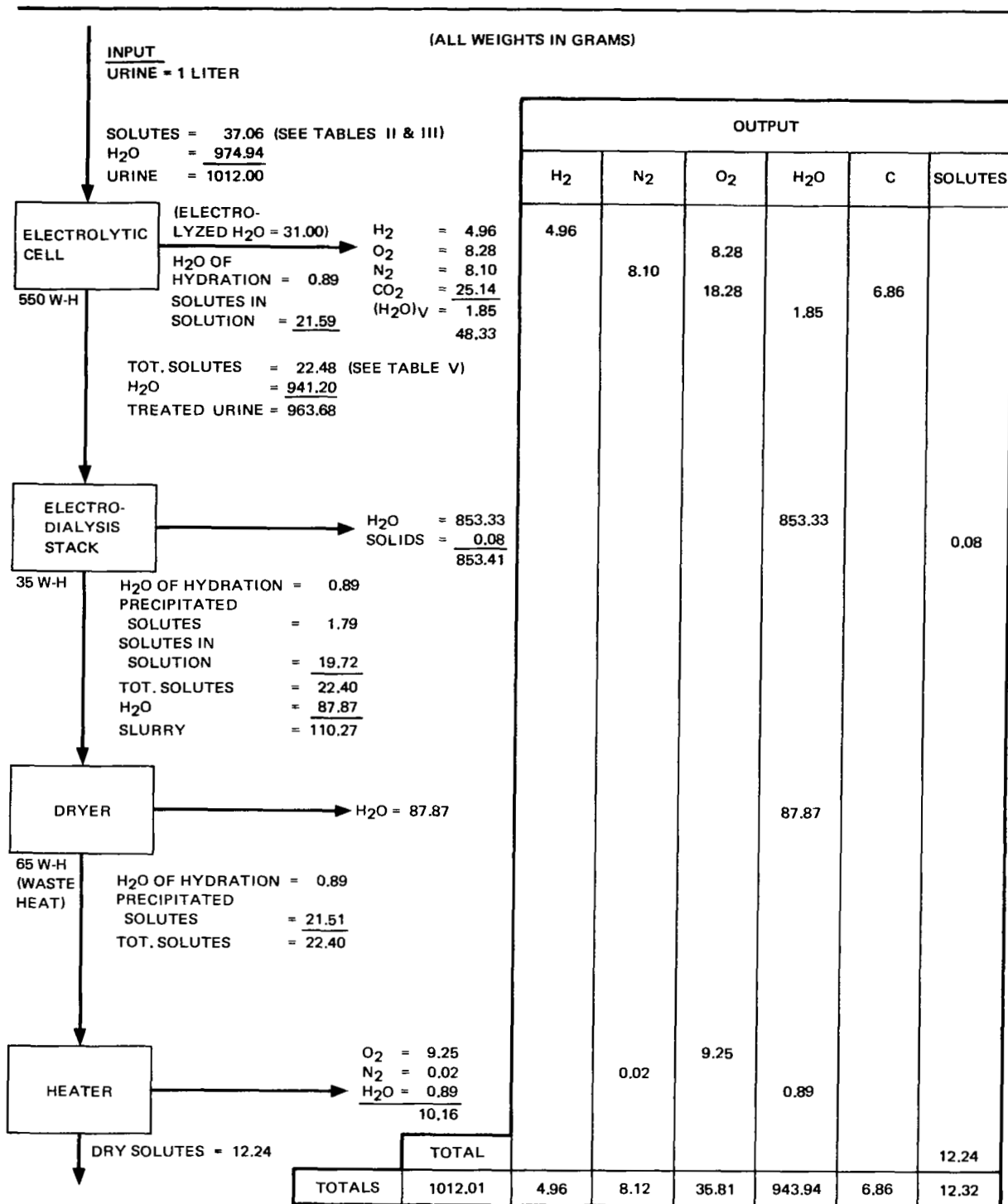


Figure 9. Mass Balance for Water Recovery From Typical Human Urine by Electropurification

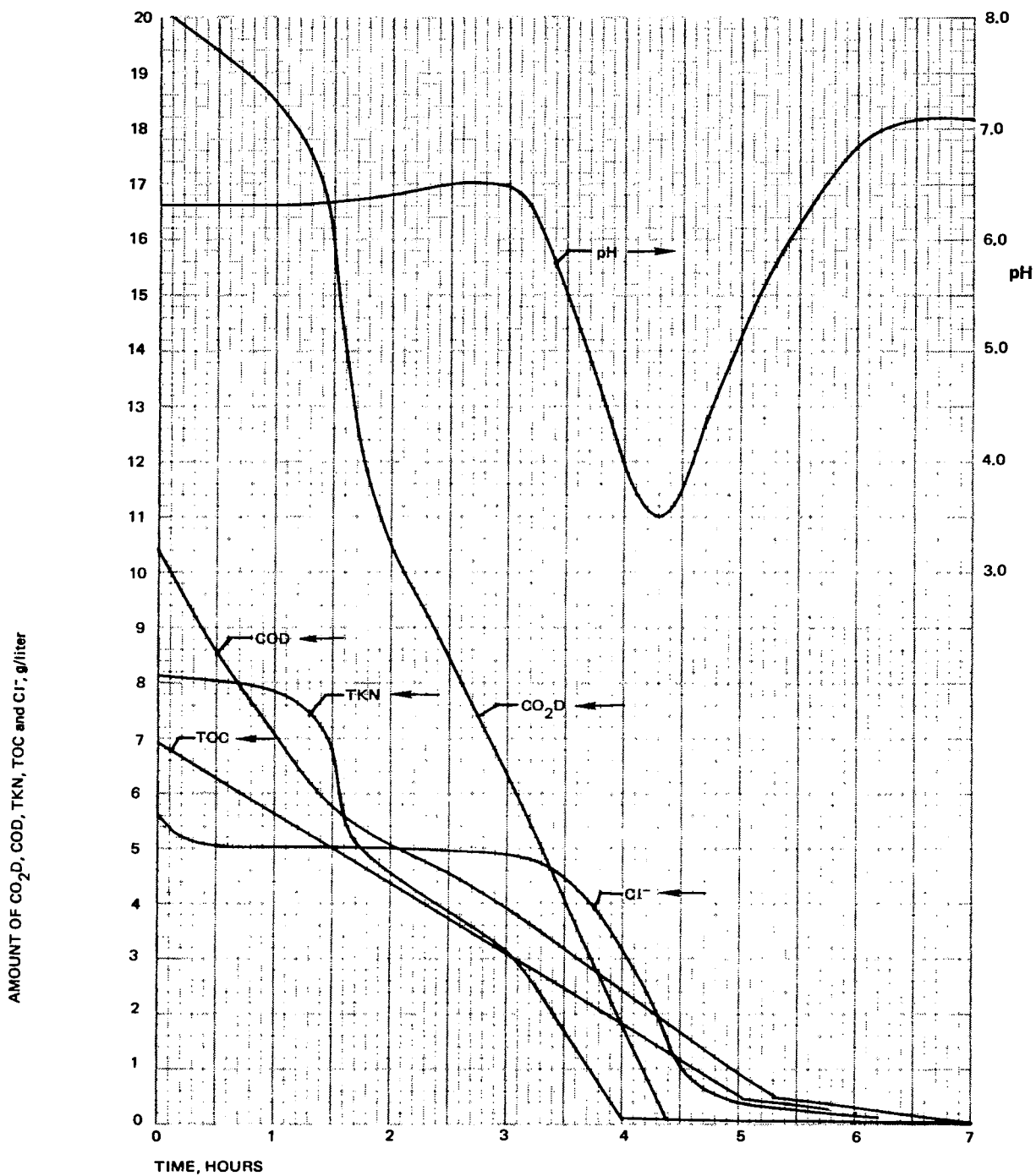


Figure 10. $\text{CO}_2\text{-D}$, COD, TKN, TOC, Cl^- and pH of Urine During Electrolytic Pretreatment

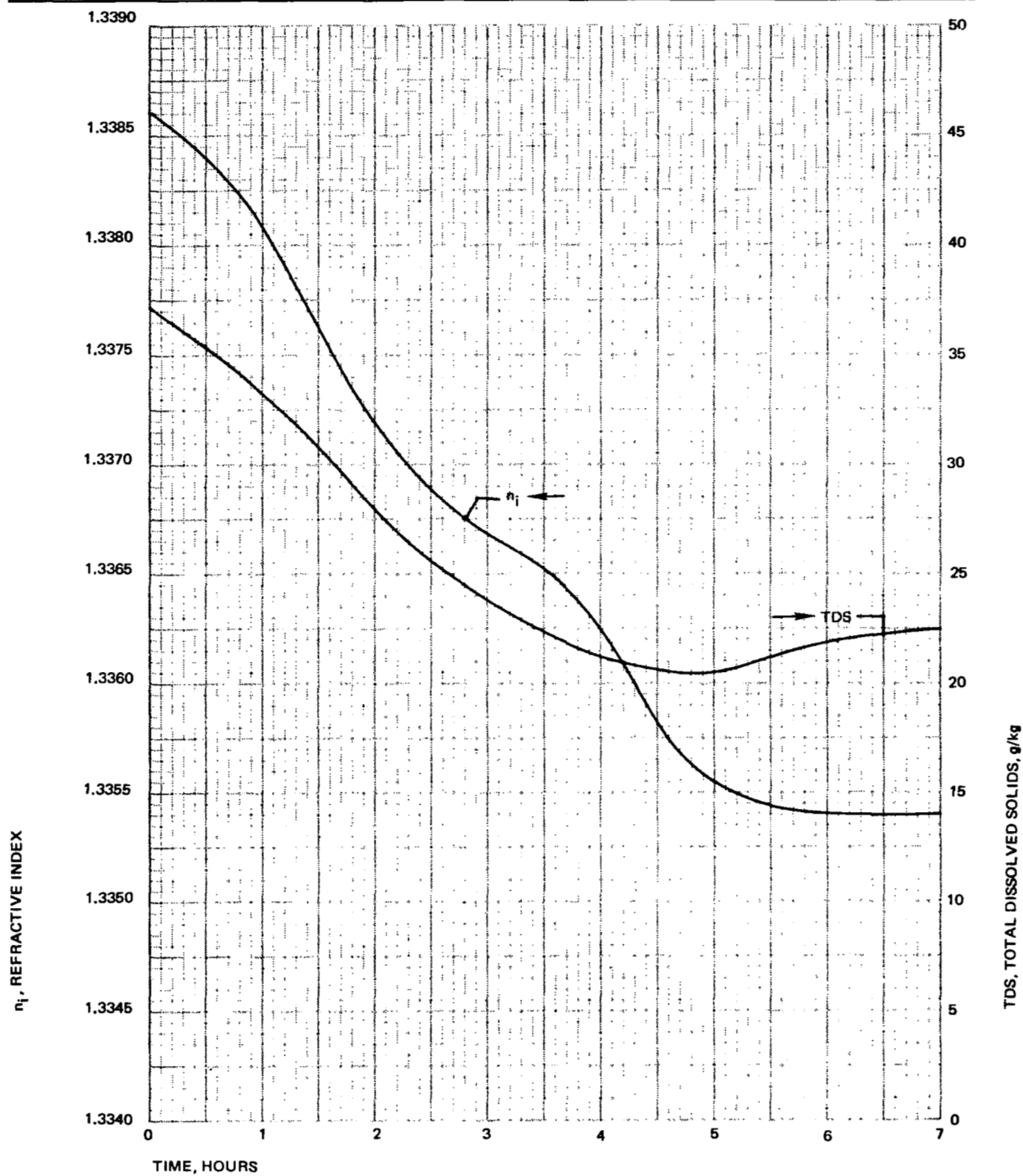


Figure 11. TDS and n_i of Urine During Electrolytic Pretreatment

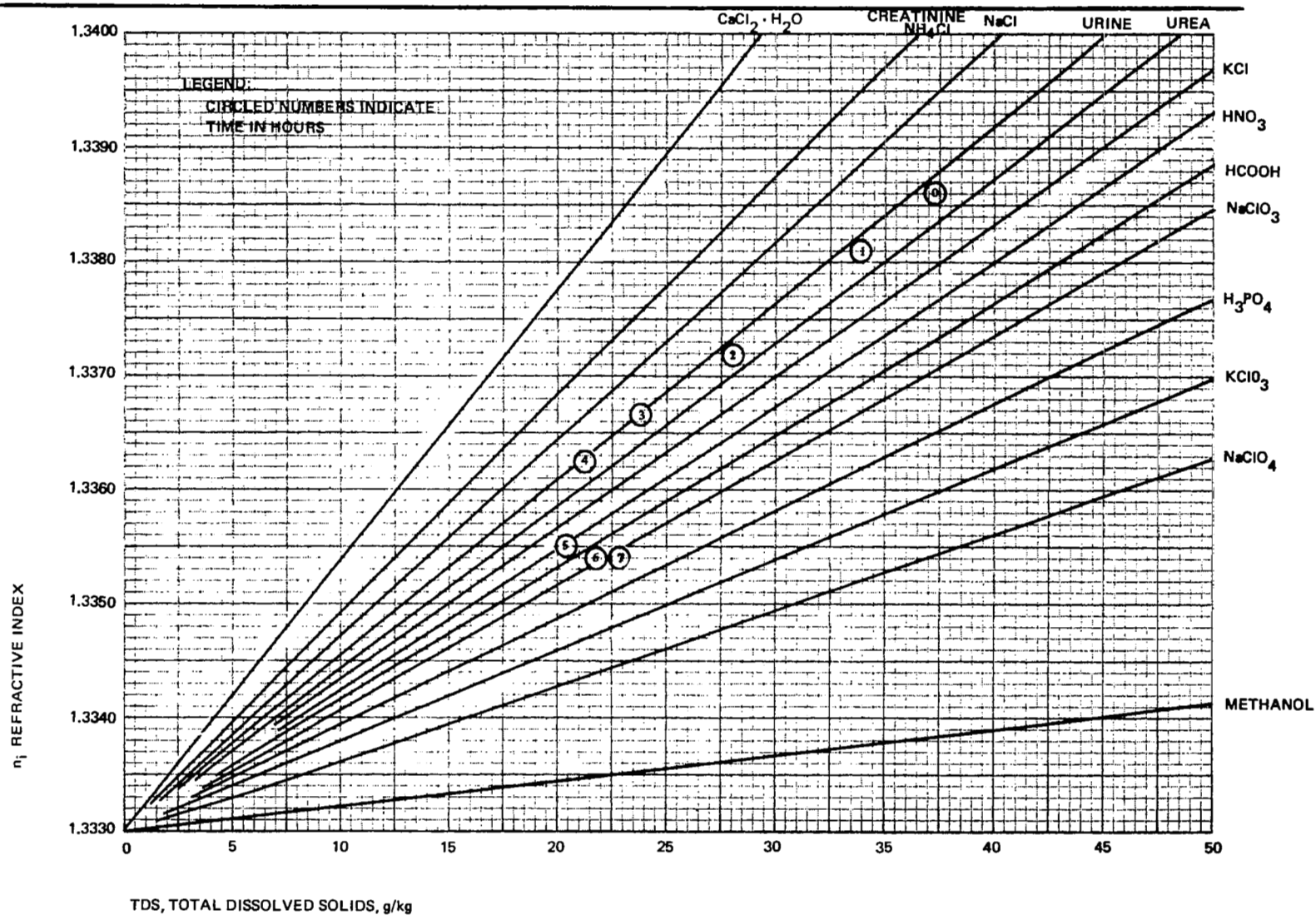


Figure 12. n_i Versus TDS of Urine During Electrolytic Pretreatment

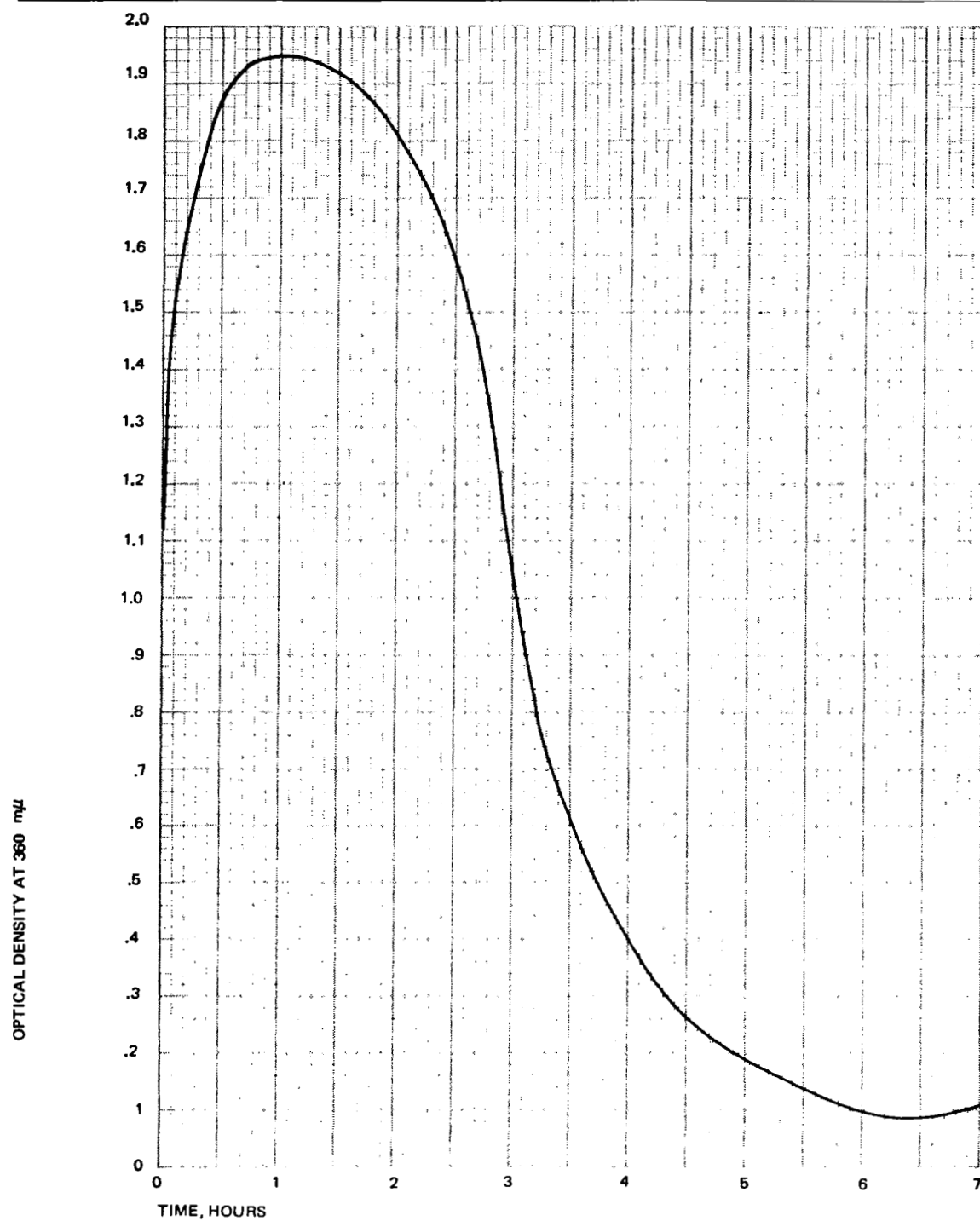


Figure 13. Optical Density of Urine During Electrolytic Pretreatment

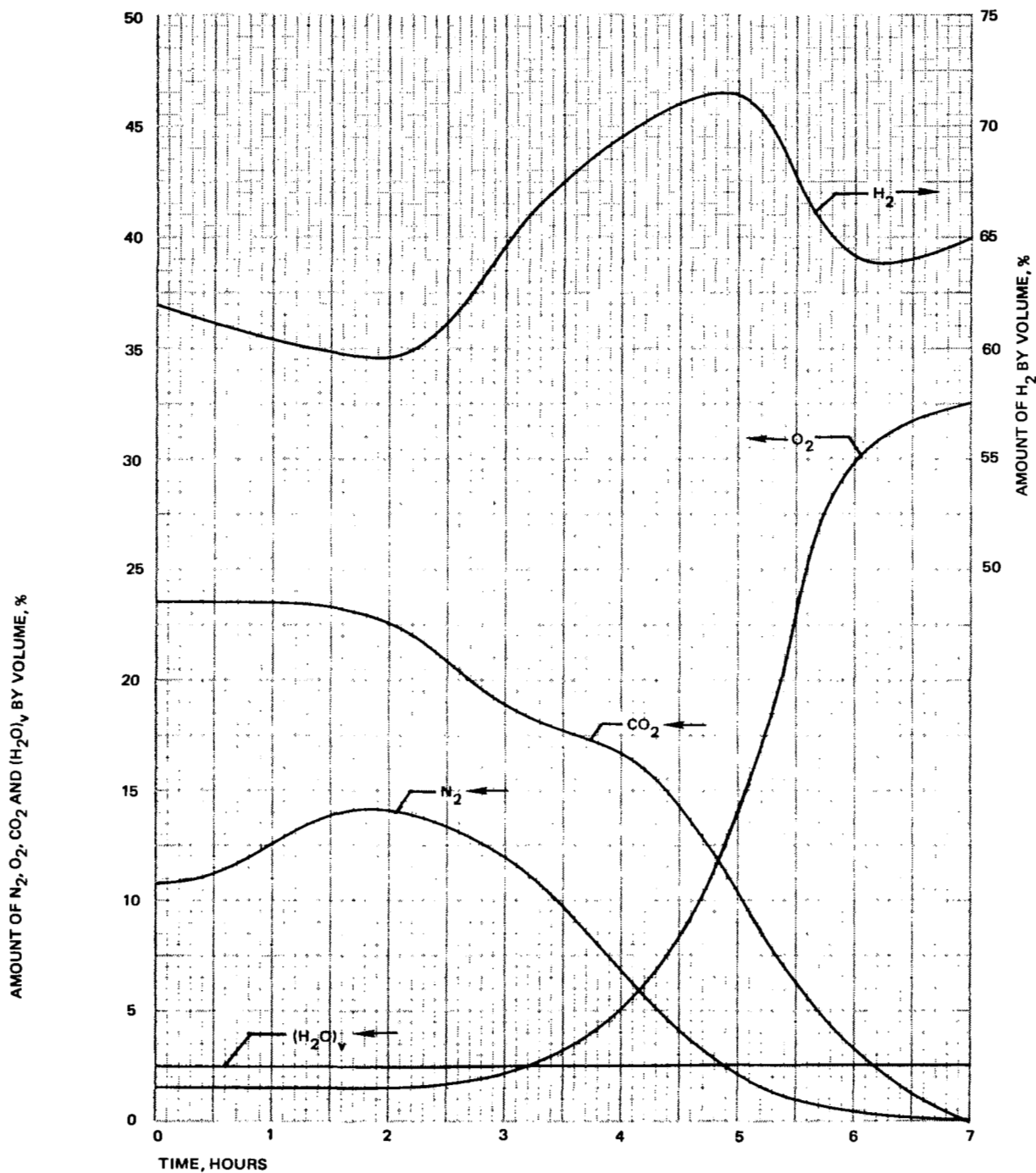


Figure 14. Composition of Gas Output During Electrolytic Pretreatment

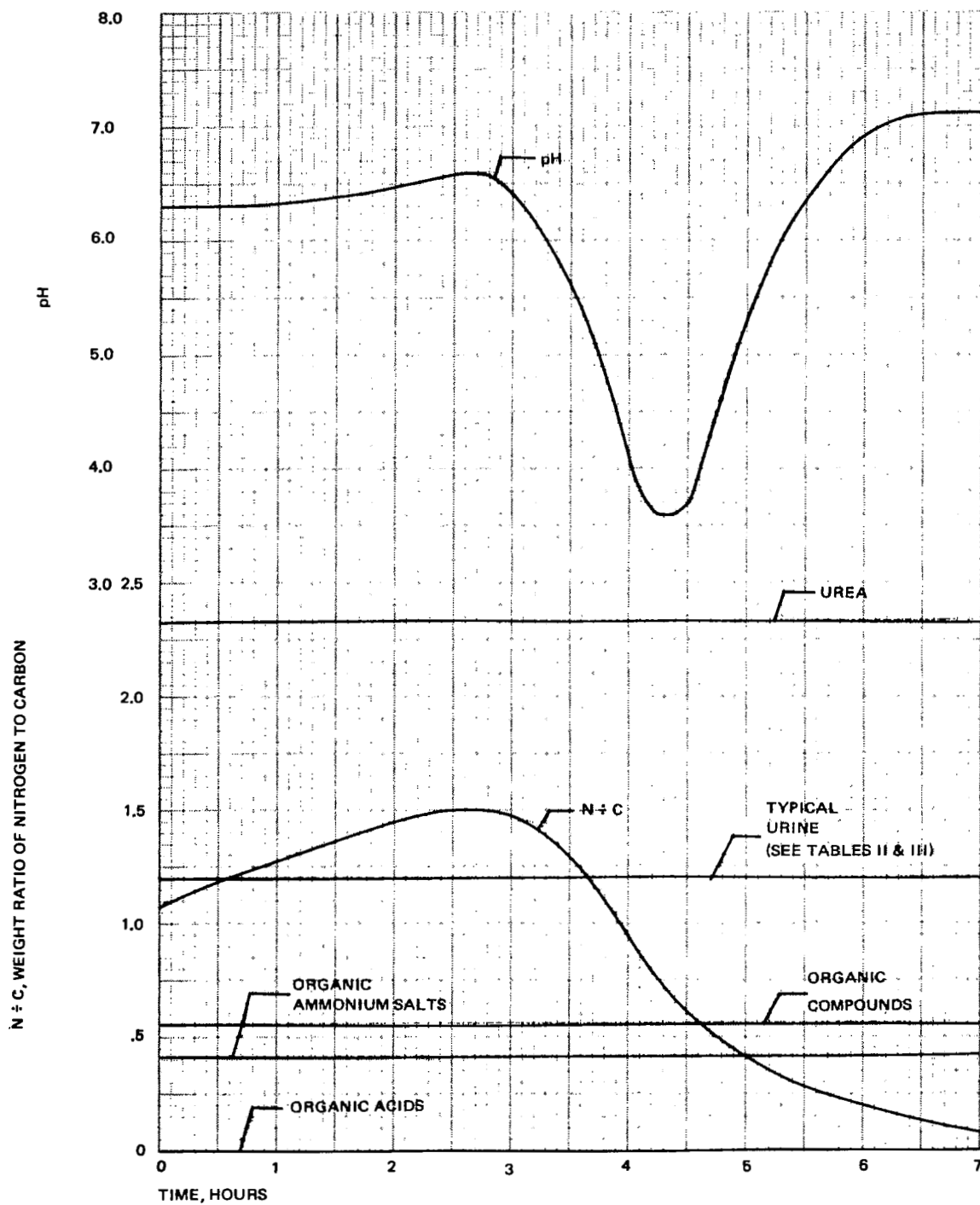


Figure 15. Ratio of Nitrogen to Carbon in Evolved Gas During Electrolytic Pretreatment

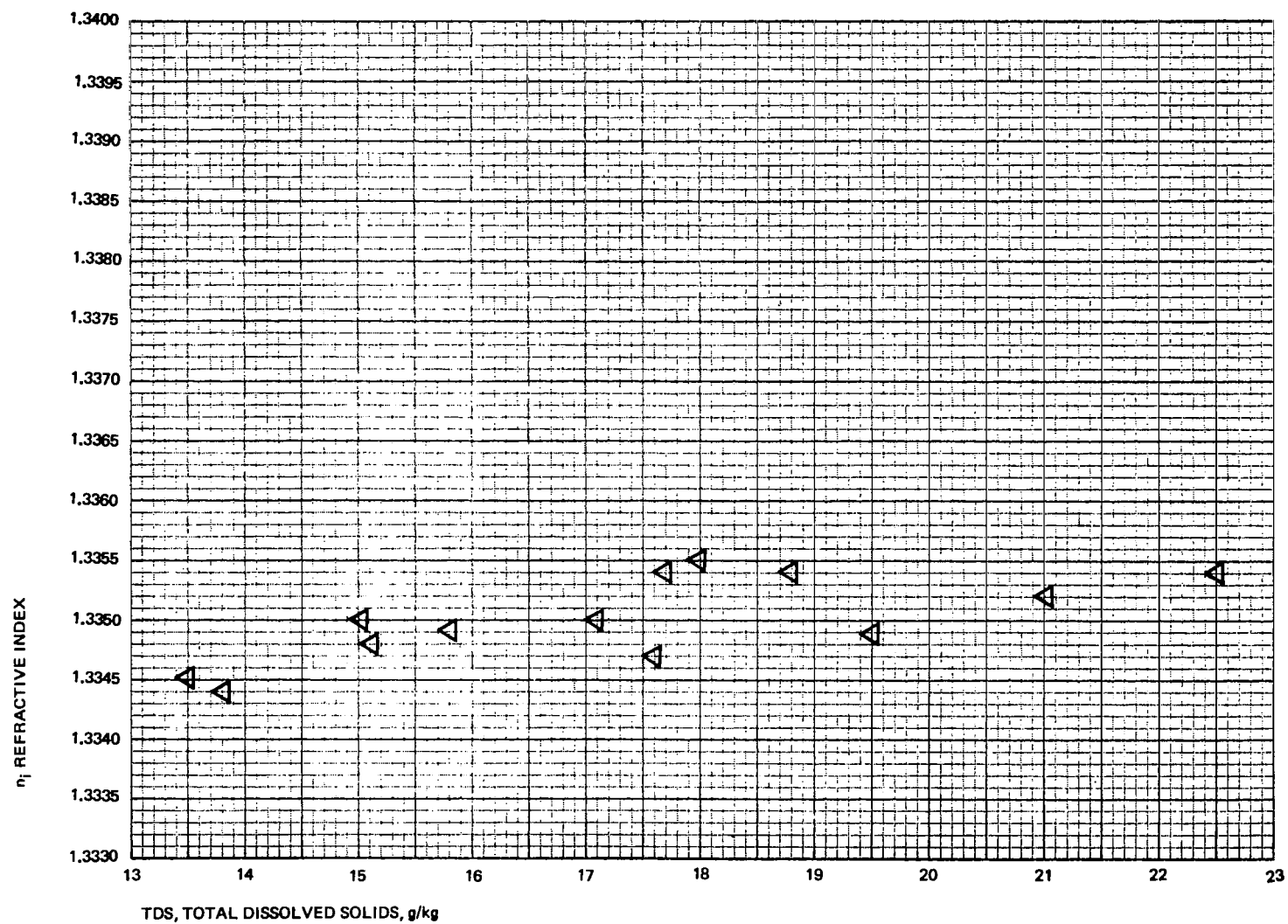


Figure 16. Refractive Index of Electrolyzed Urine

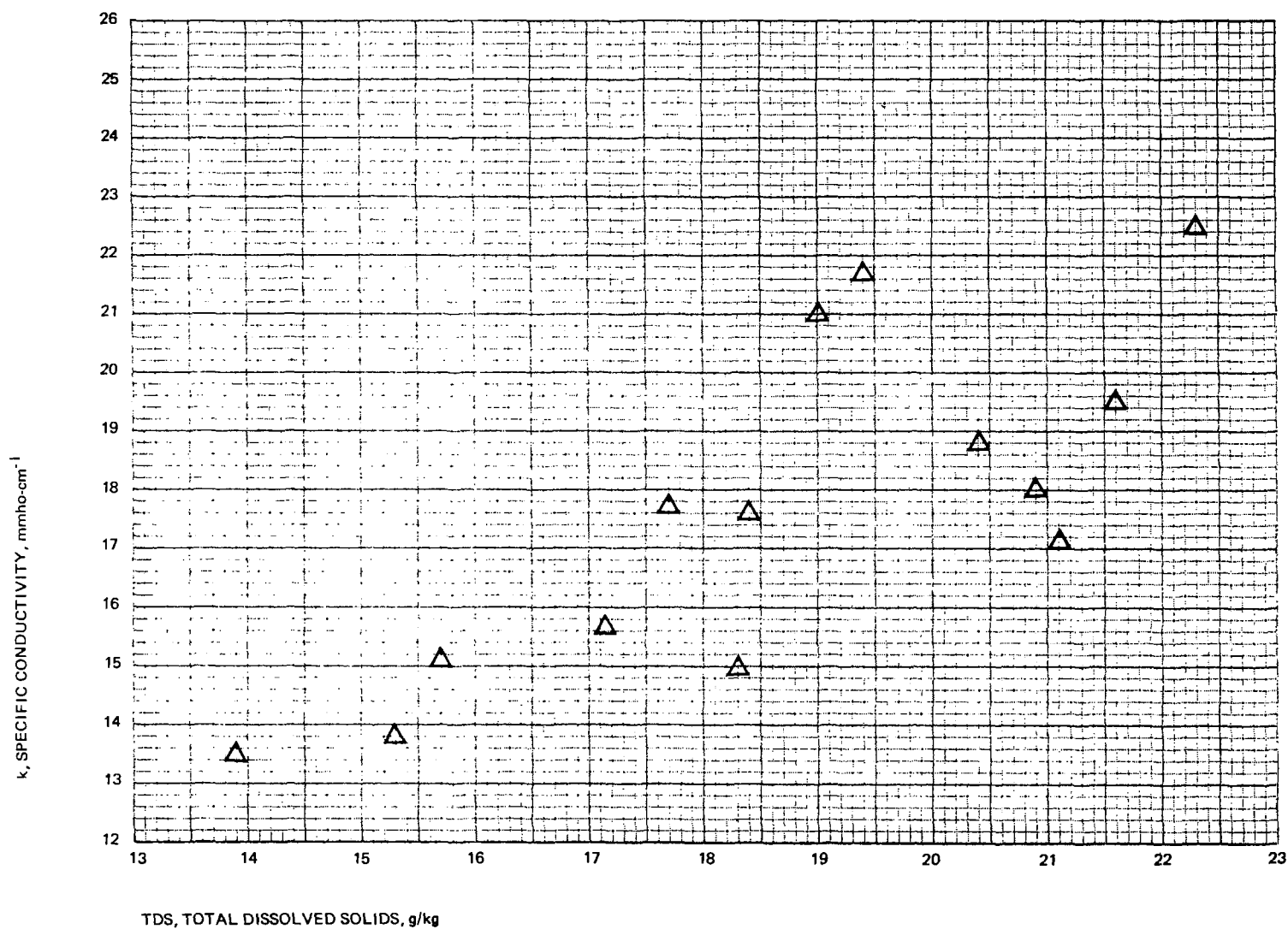


Figure 17. Specific Conductivity of Electrolyzed Urine

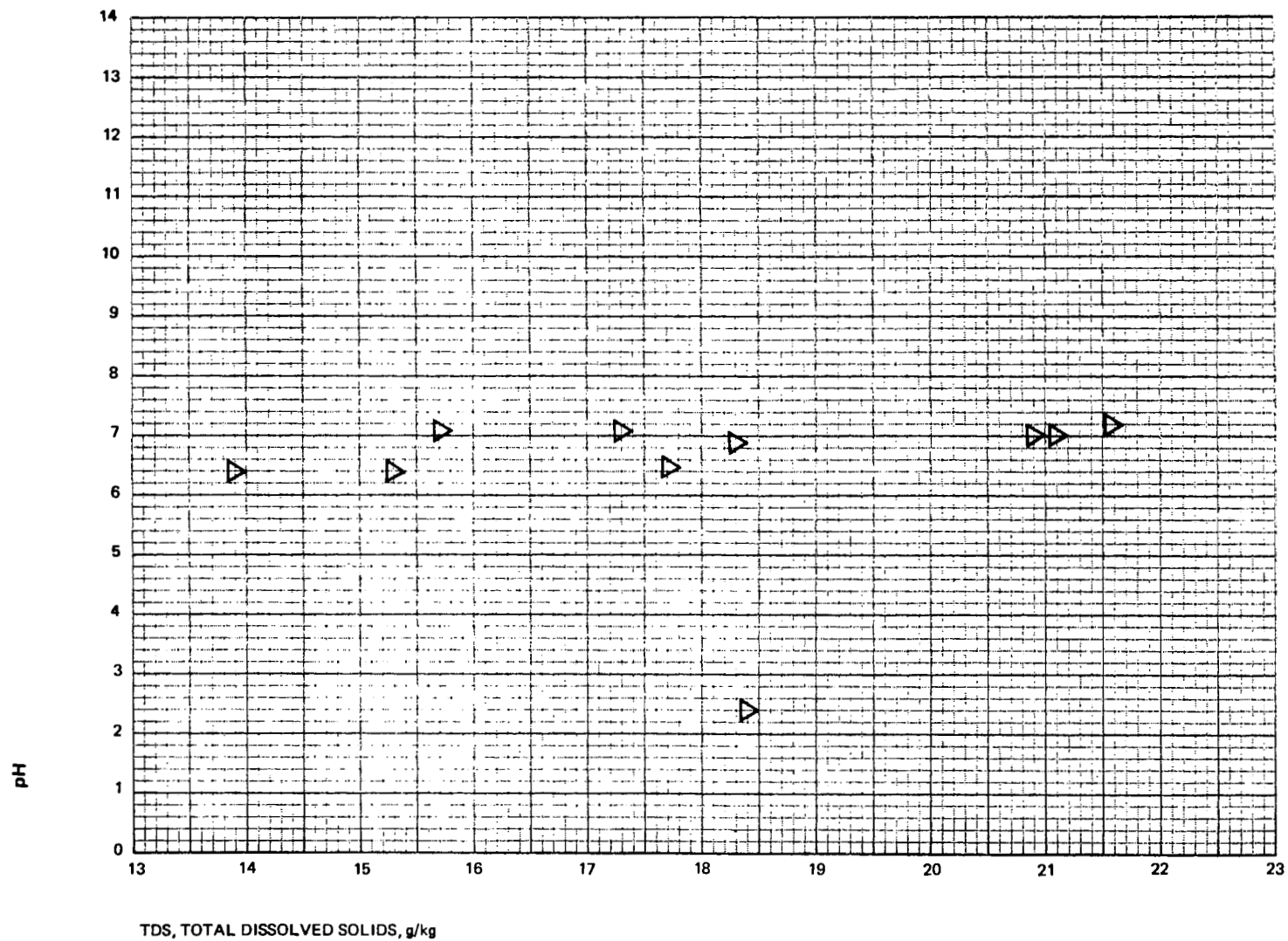


Figure 18. pH of Electrolyzed Urine

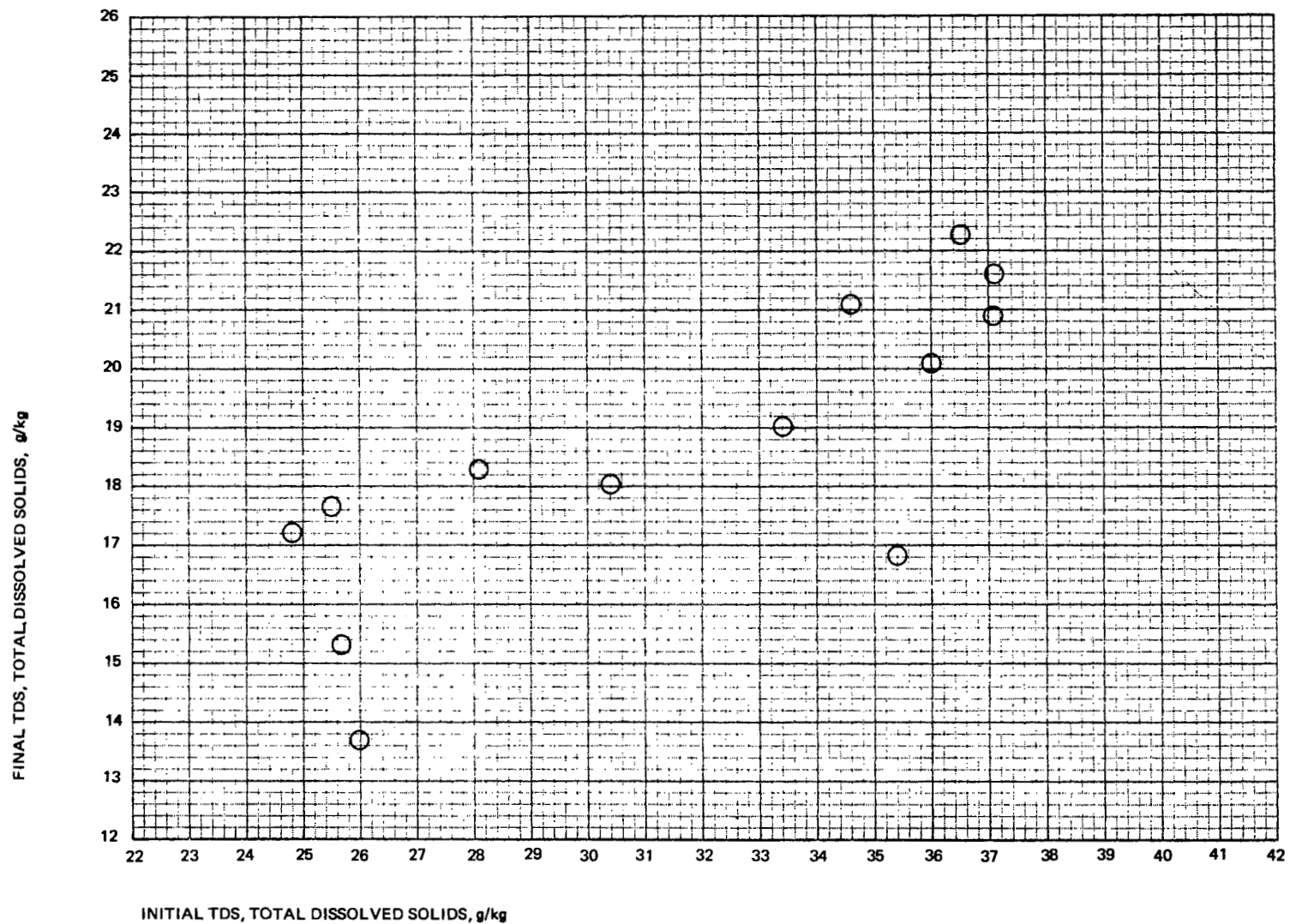


Figure 19. Final Versus Initial TDS of Electrolyzed Urine

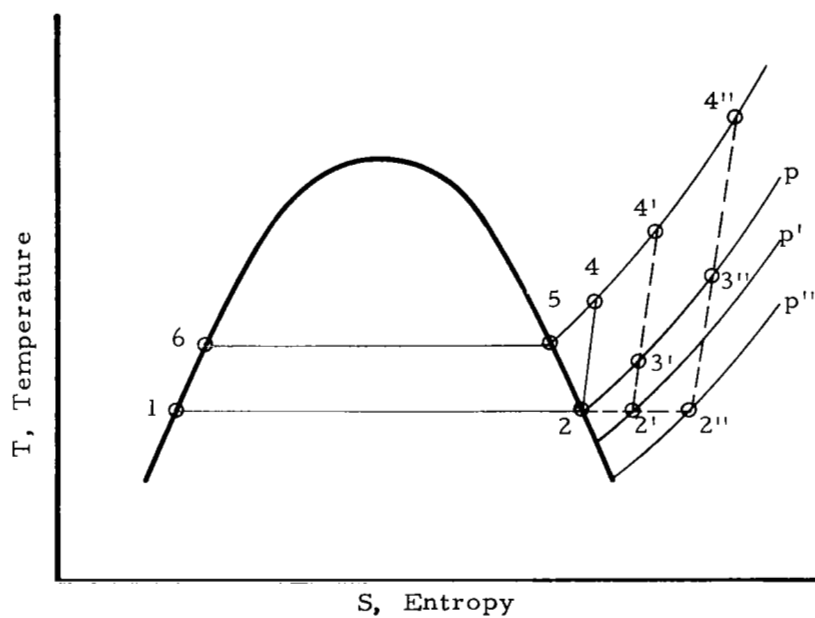


Figure 20. T-S Diagram of Vapor Compression Process

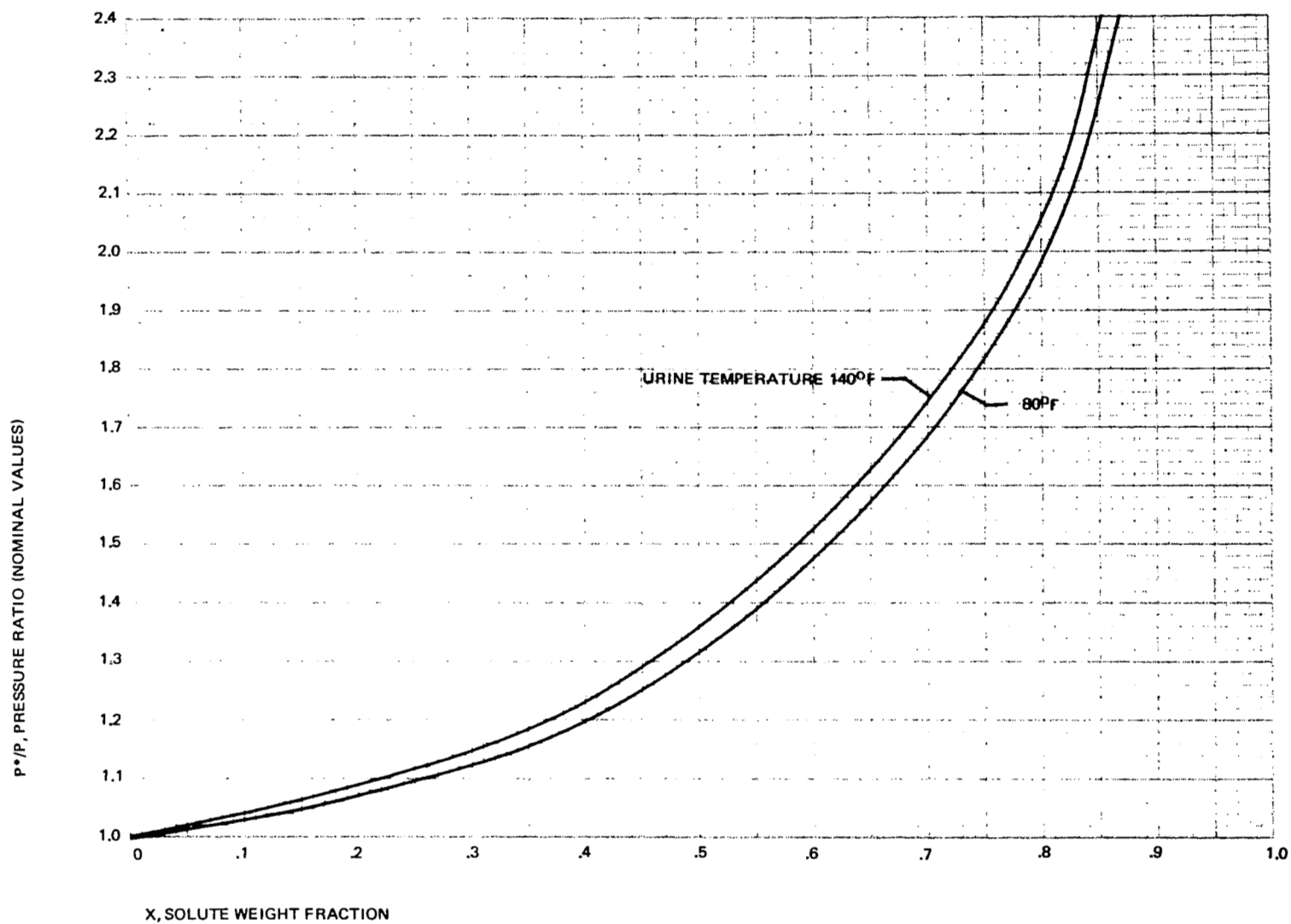


Figure 21. Ratio of the Vapor Pressure of Pure Water to the Vapor Pressure of Urine Concentrate

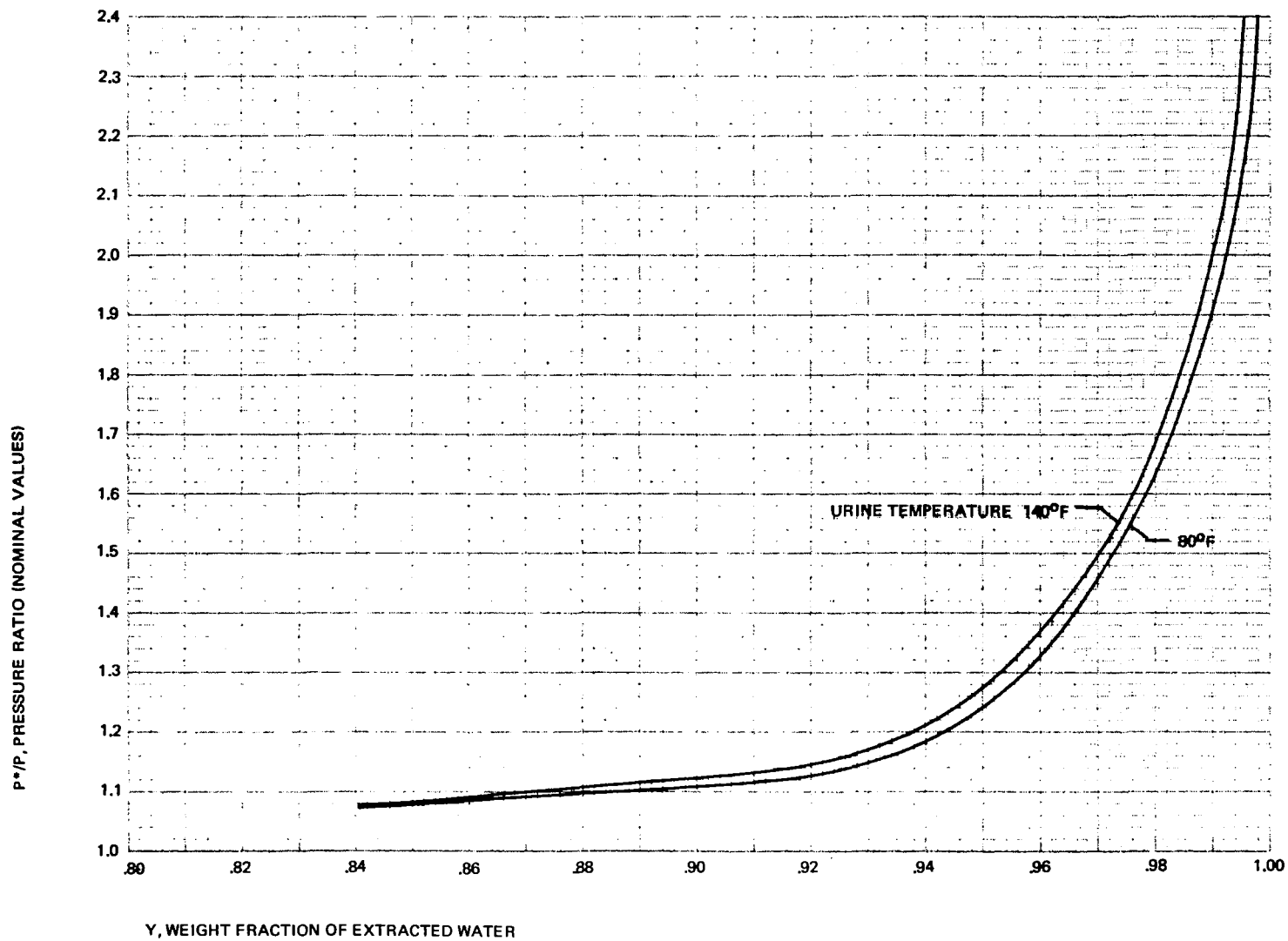


Figure 22. Pressure Ratio as a Function of the Weight Fraction of Extracted Water

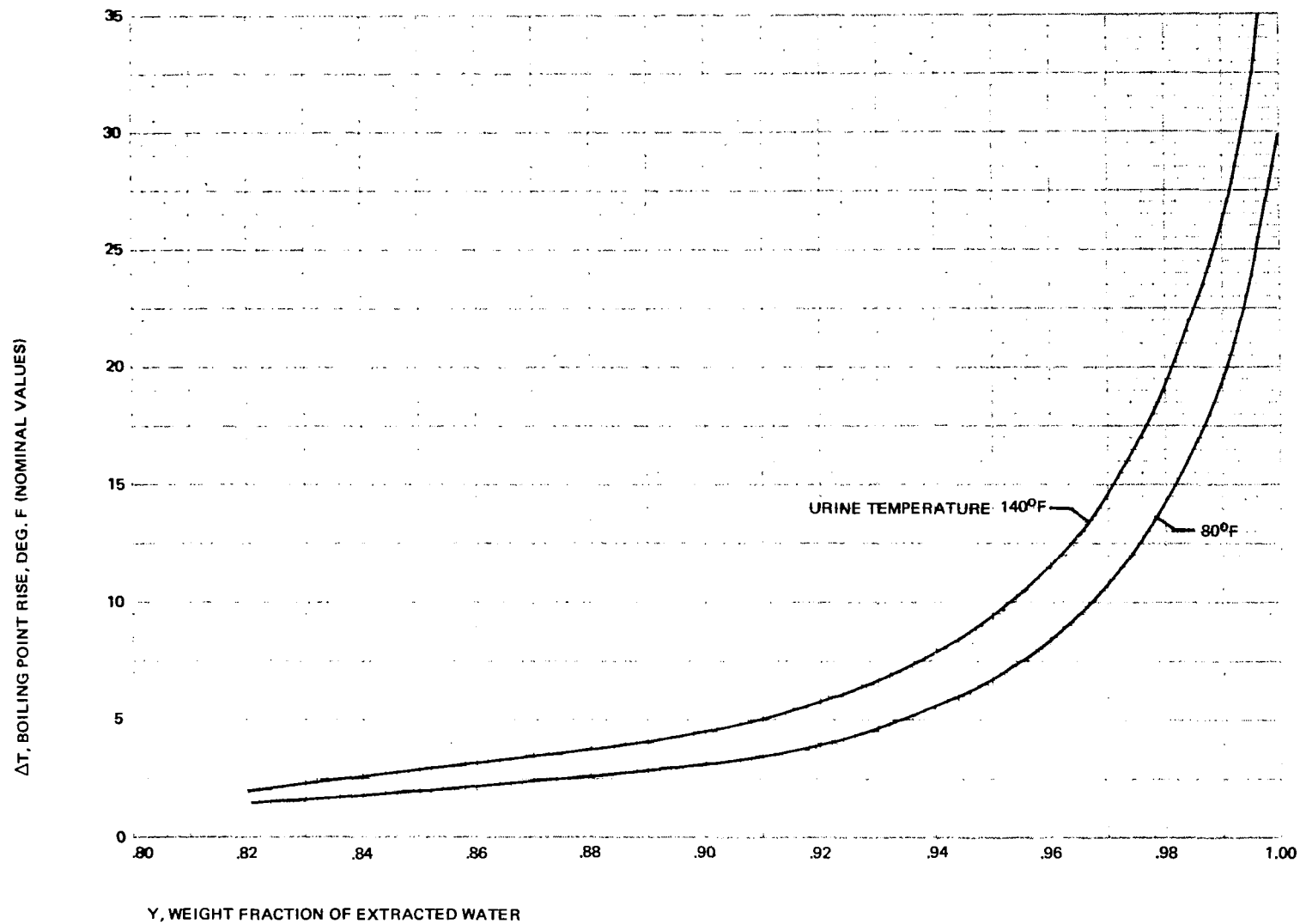


Figure 23. Boiling Point Rise as a Function of the Weight Fraction of Extracted Water

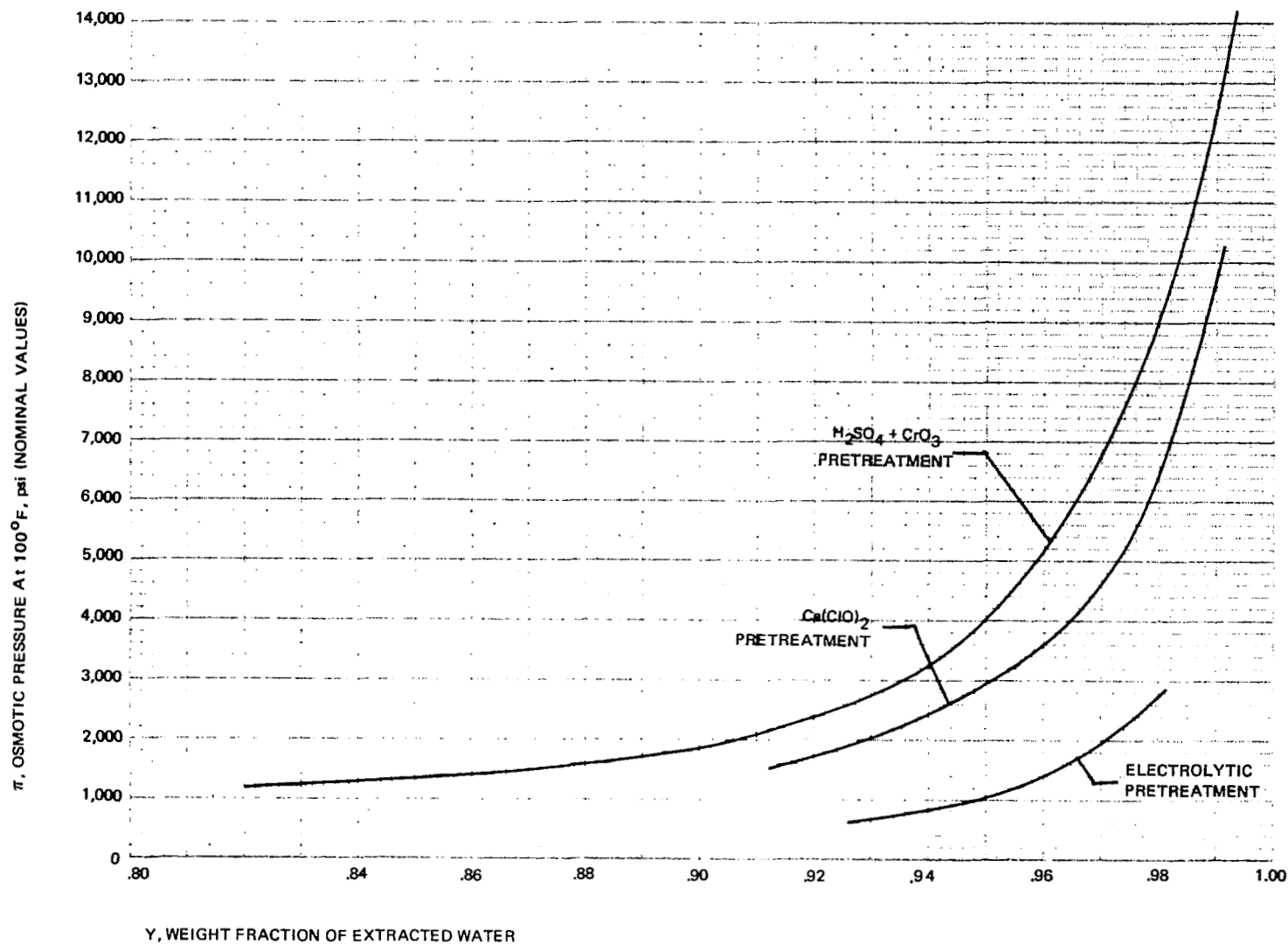


Figure 24. Osmotic Pressure as a Function of the Weight Fraction of Extracted Water

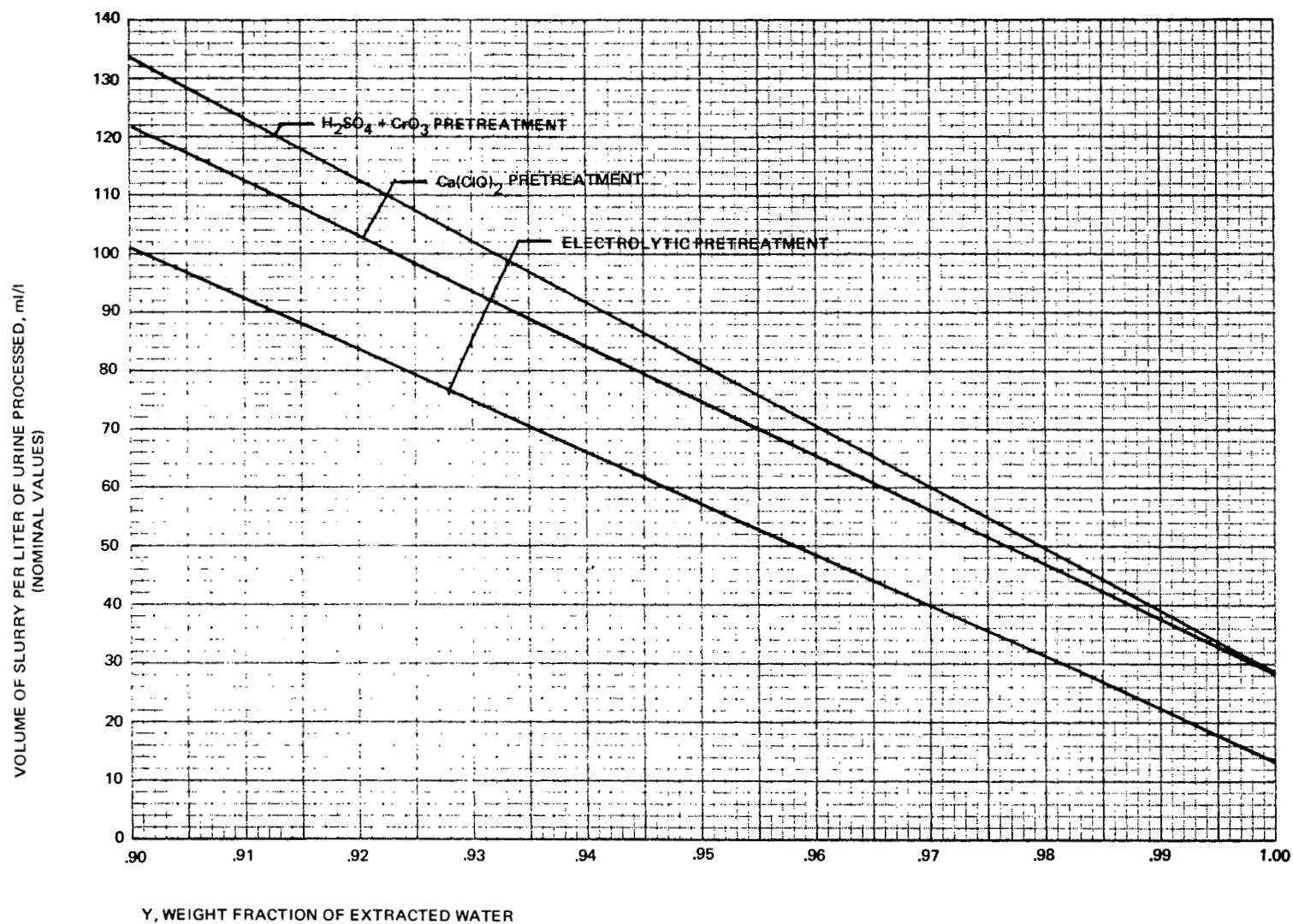


Figure 25. Volume of Urine Concentrate Slurry as a Function of the Weight Fraction of Extracted Water

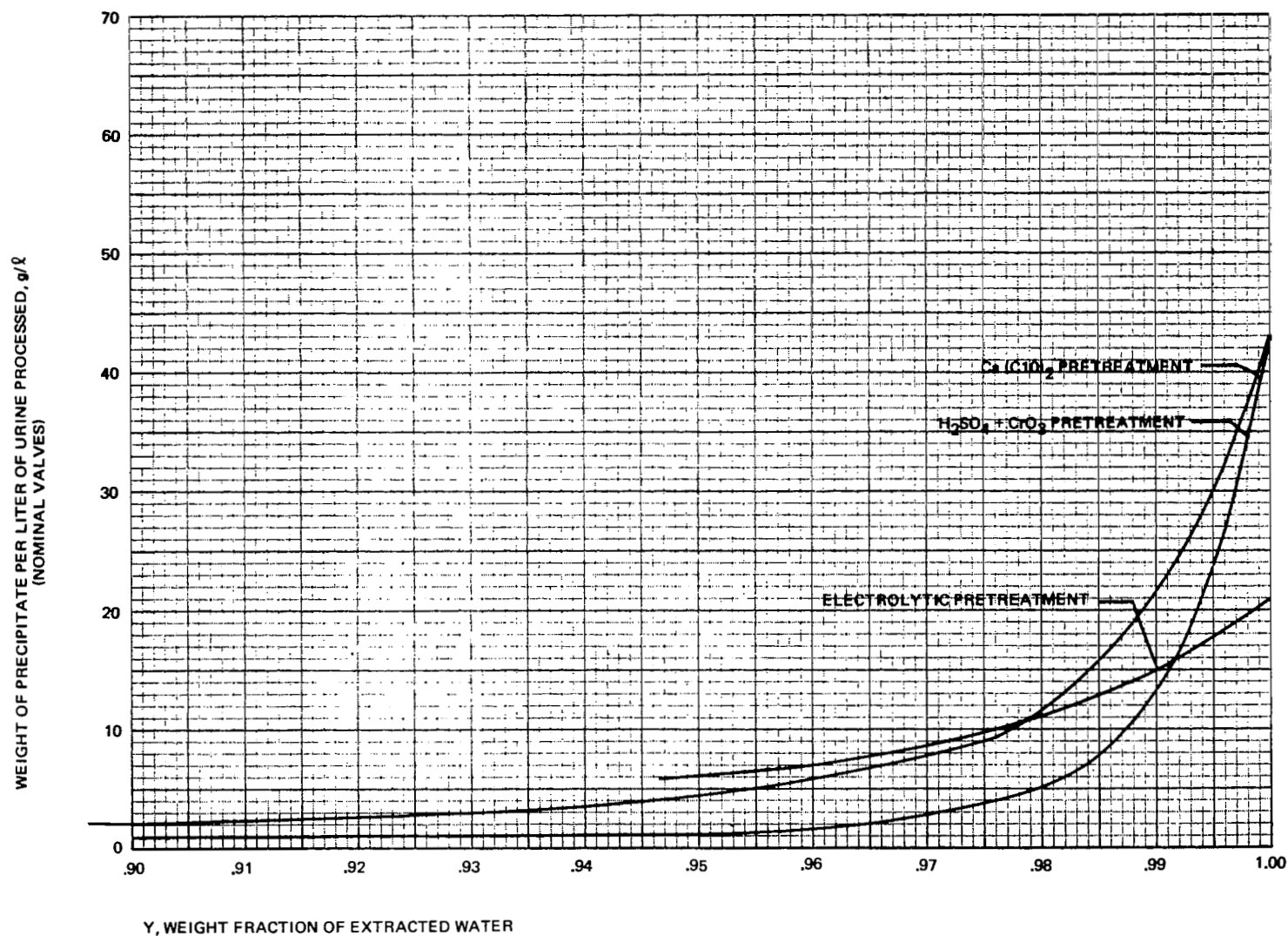


Figure 26. Weight Fraction of Precipitated Solids as a Function of the Weight Fraction of Extracted Water

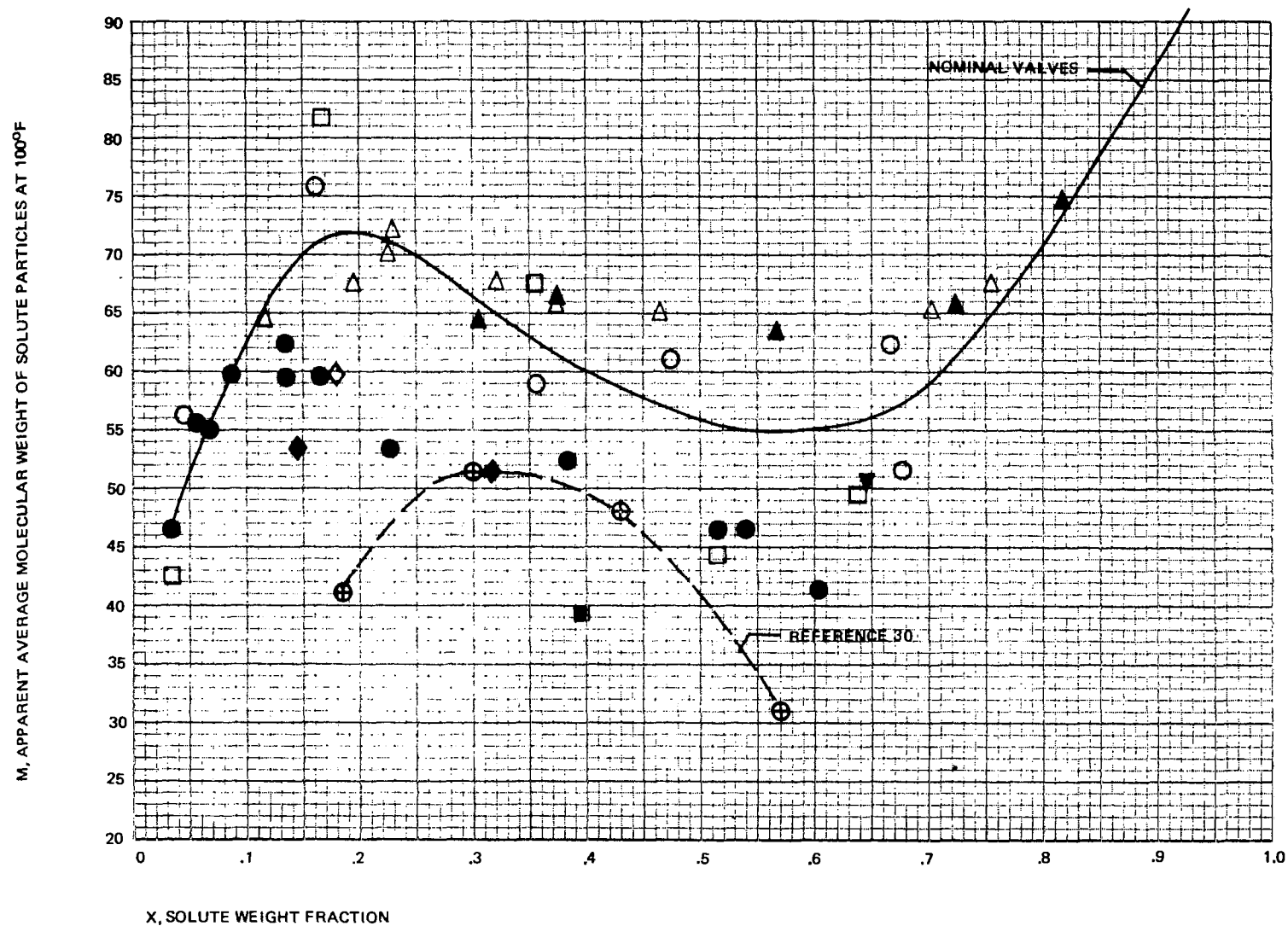


Figure 27. Apparent Average Molecular Weight of Urine Solute Particles

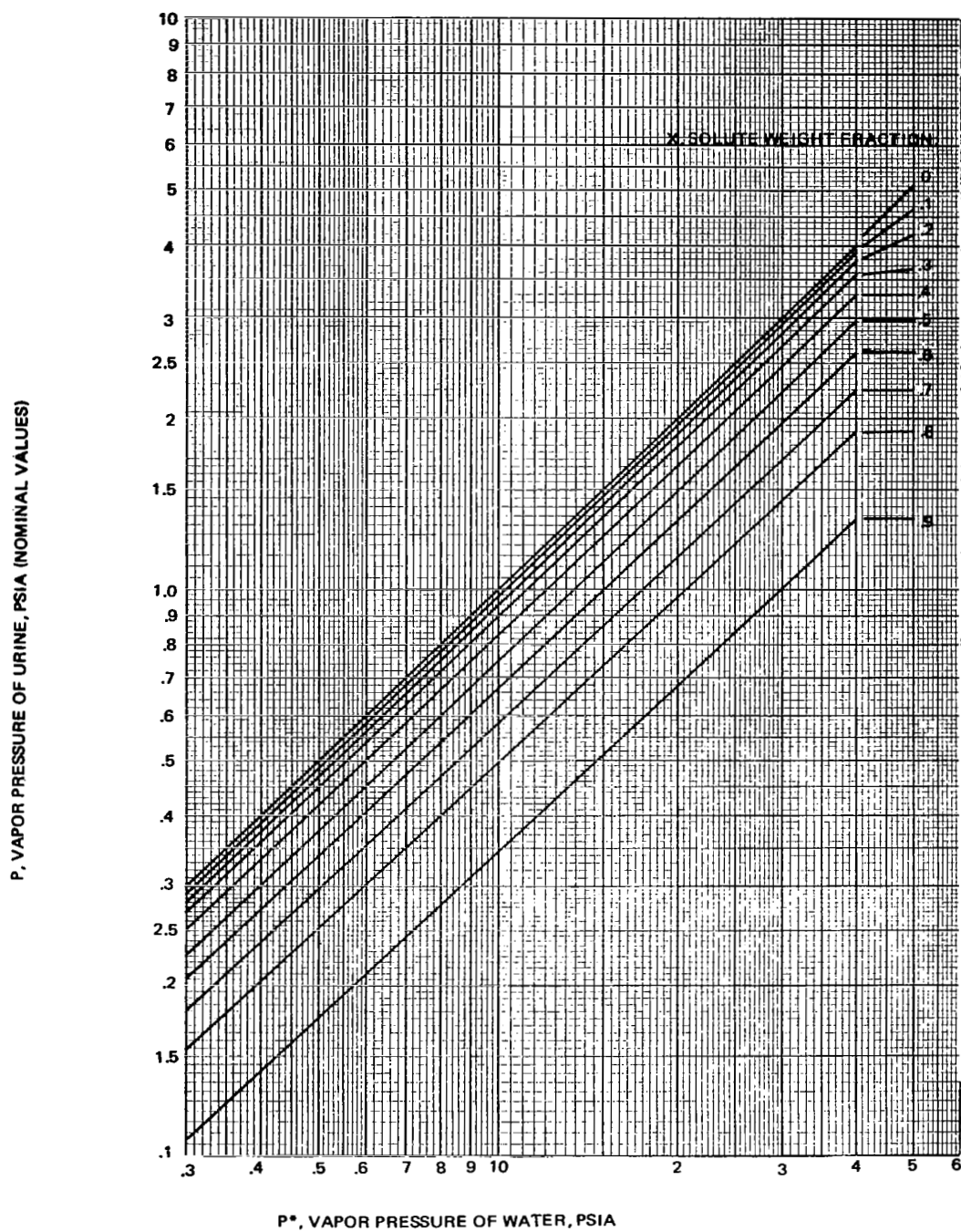


Figure 28. Logarithmic Plot of the Vapor Pressure of Urine Concentrates Versus the Vapor Pressure of Pure Water

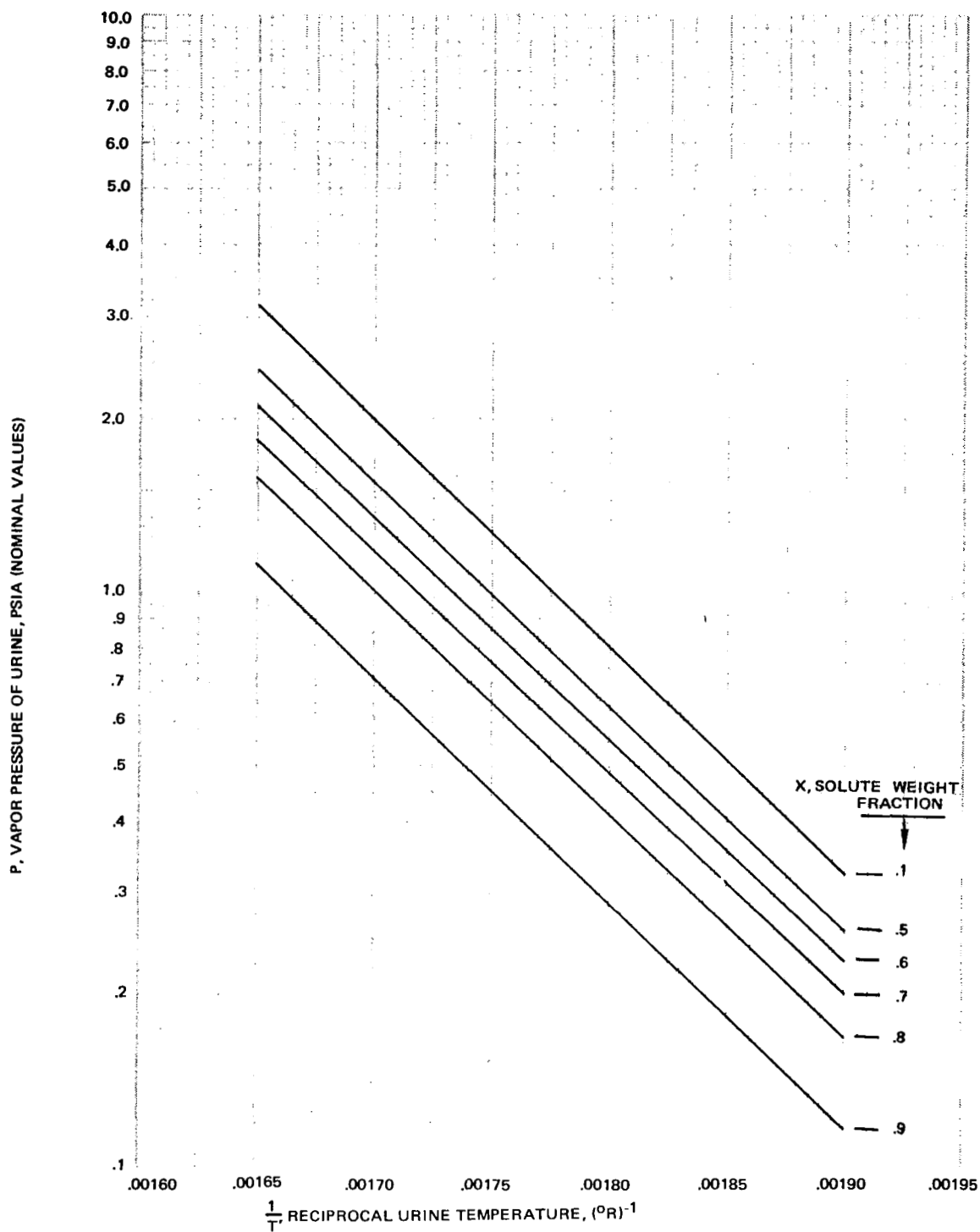


Figure 29. Semilogarithmic Plot of the Vapor Pressure of Urine Concentrates Versus the Reciprocal of the Boiling Temperature

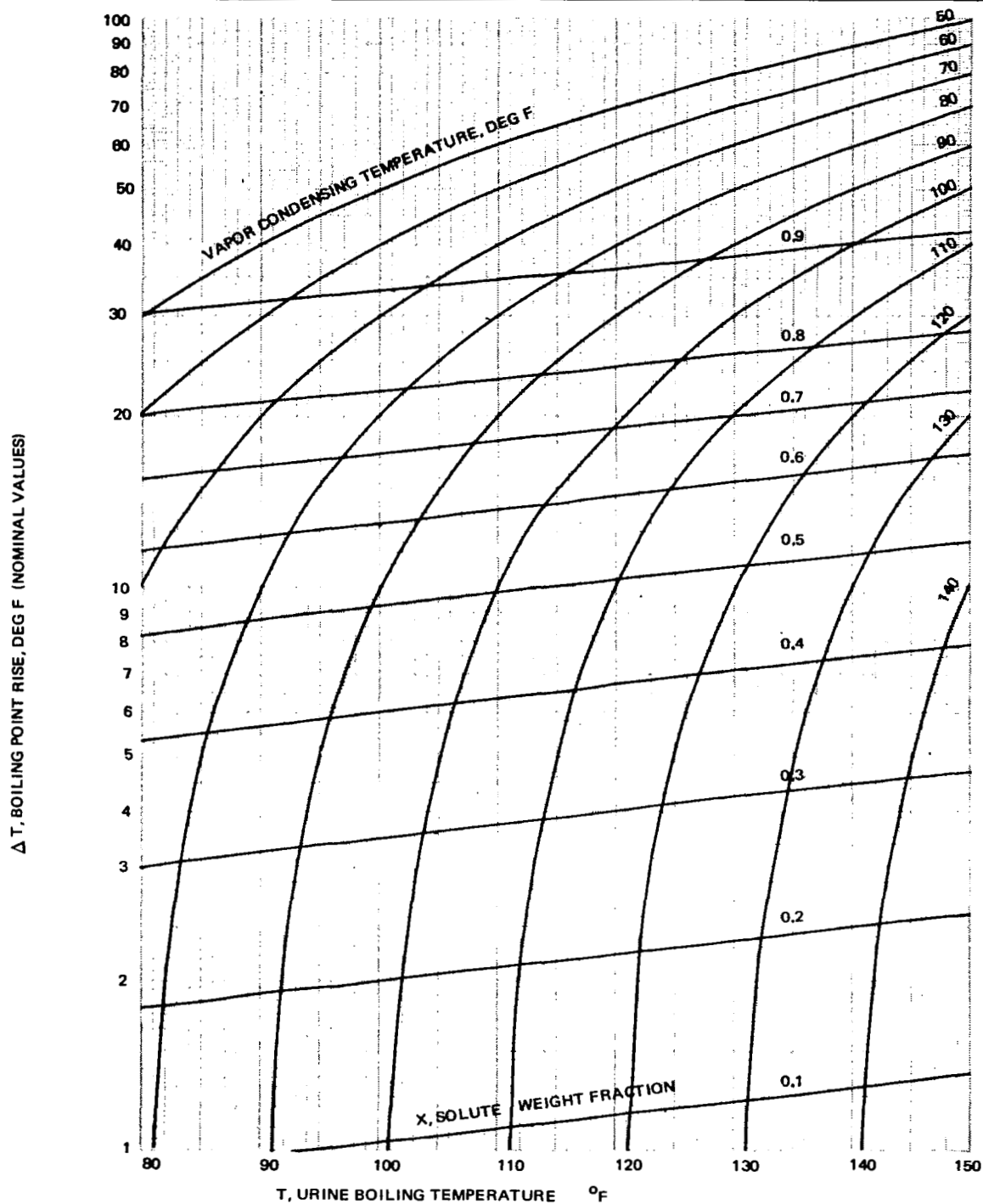


Figure 30. Boiling Point Rise as a Function of Boiling Temperature, Condensing Temperature, and Solute Weight Fraction

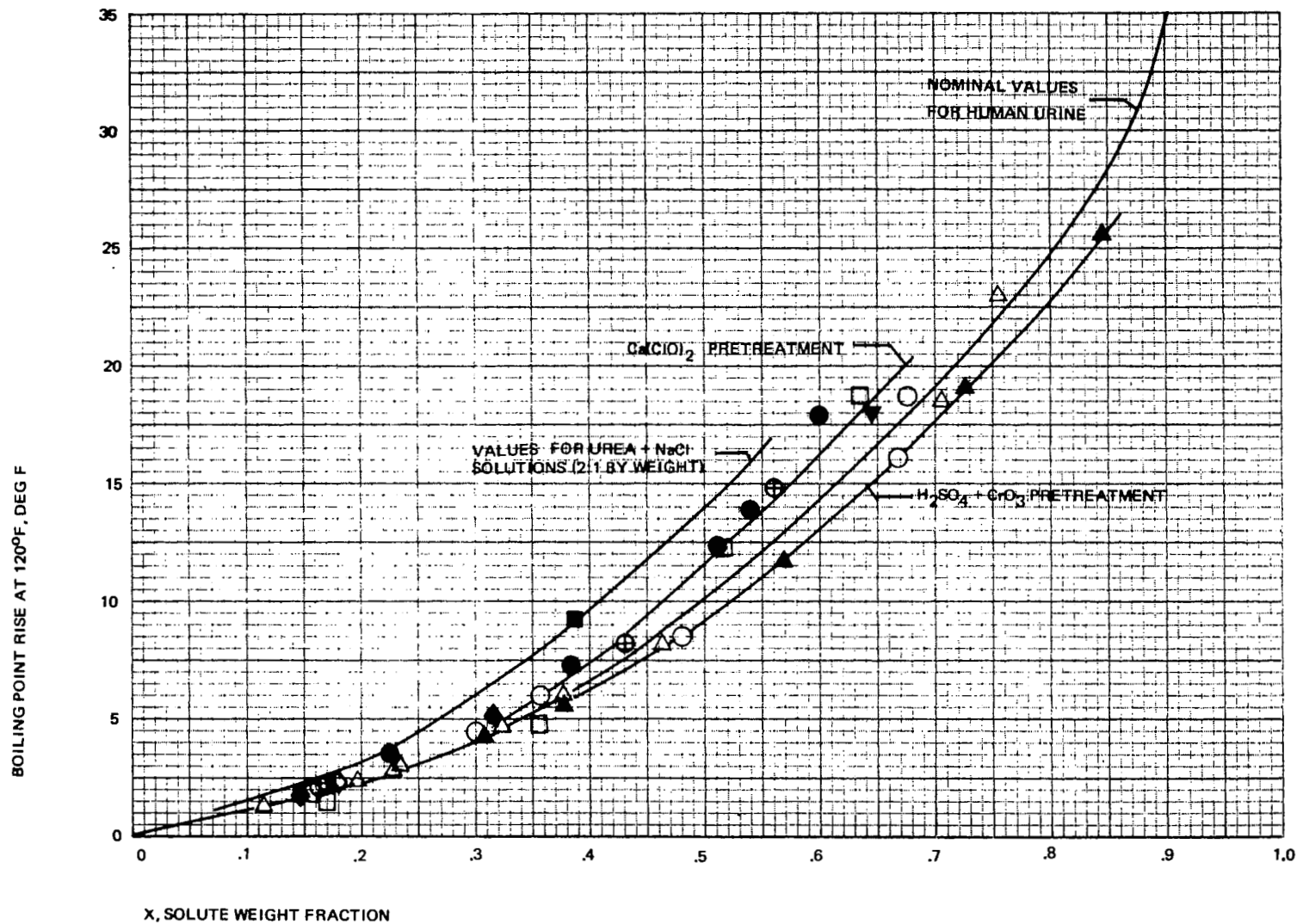


Figure 31. Boiling Point Rise of Urine Concentrate

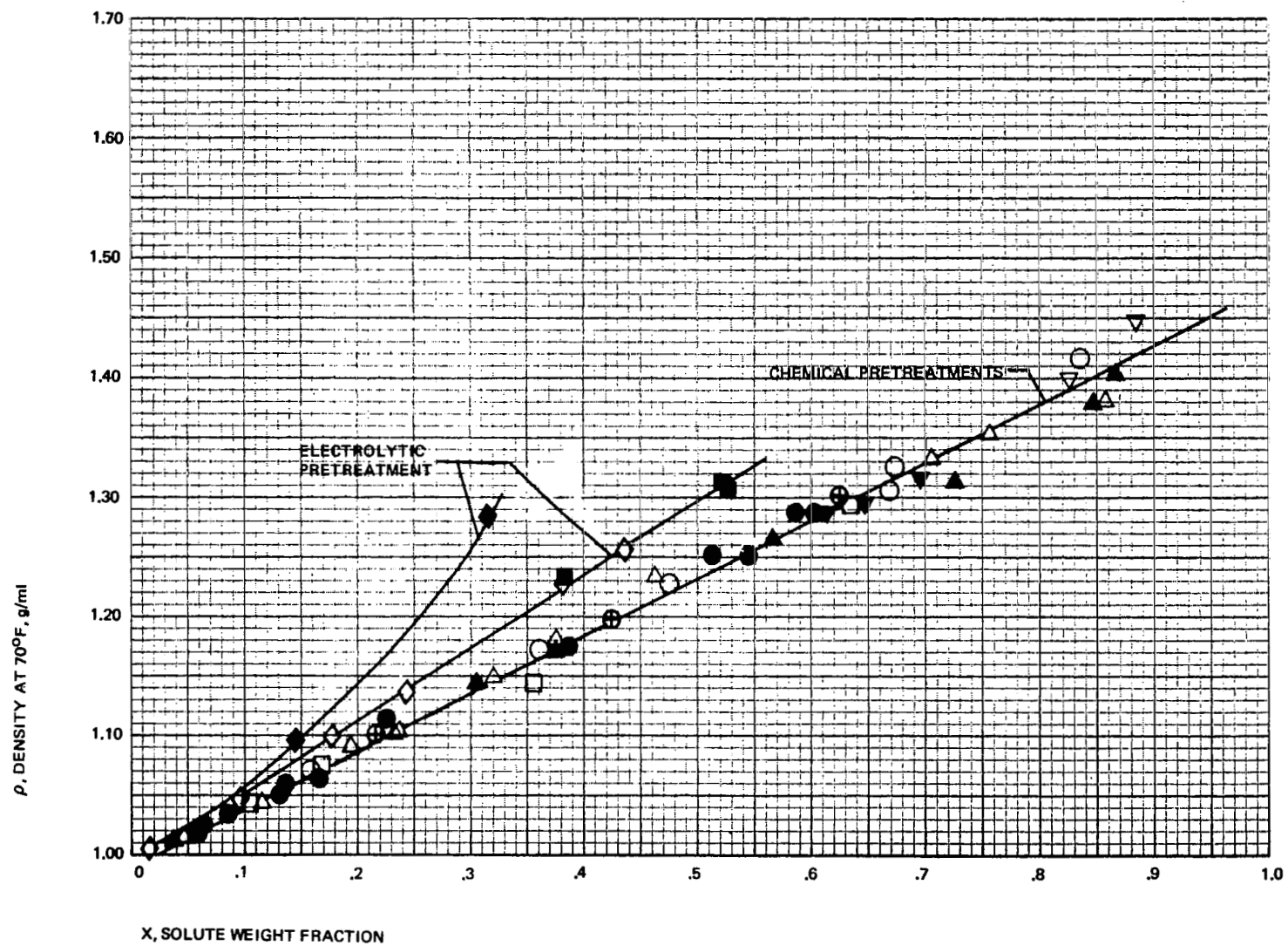


Figure 32. Density of Urine Concentrate

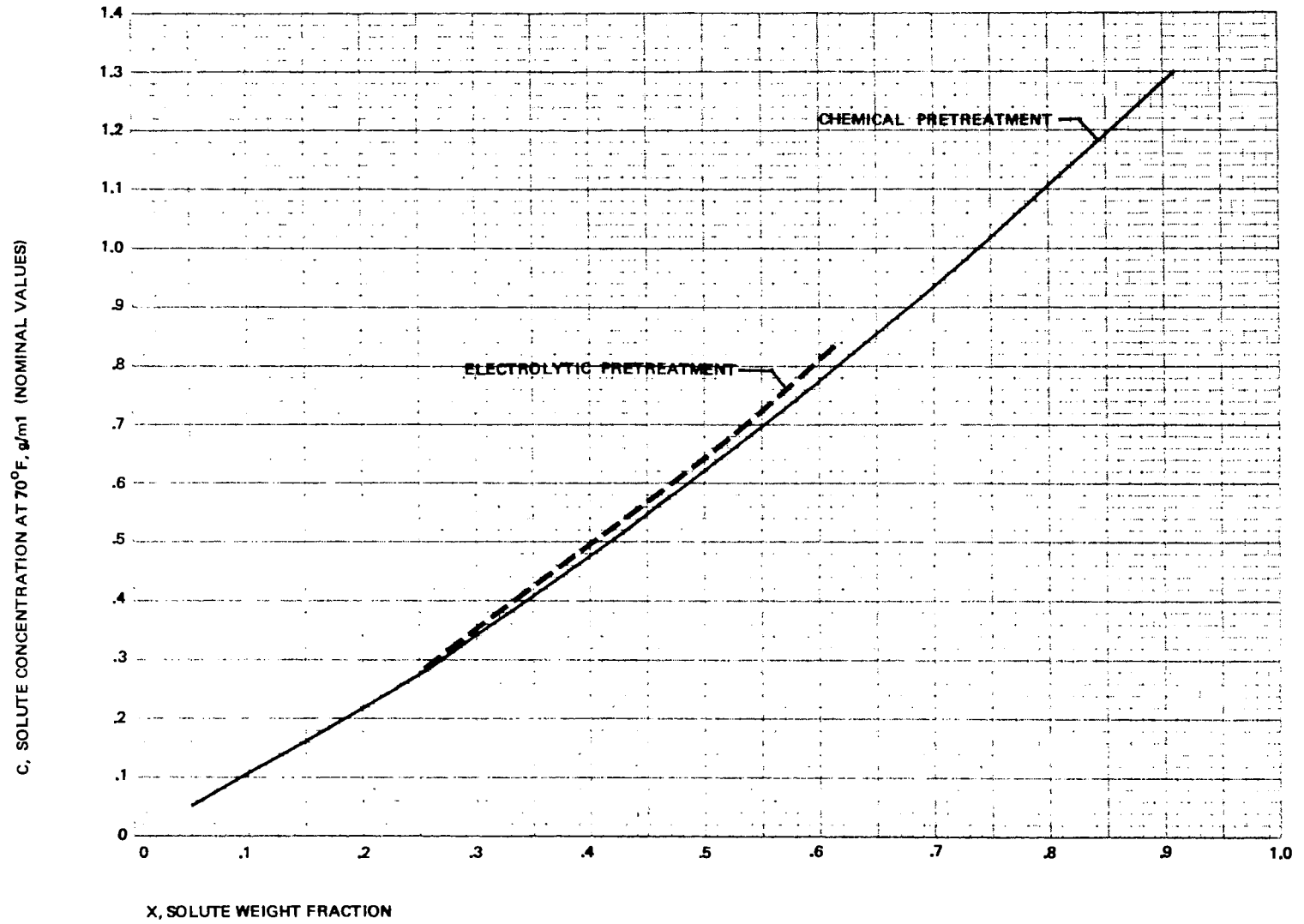


Figure 33. Solute Concentration of Urine Concentrate

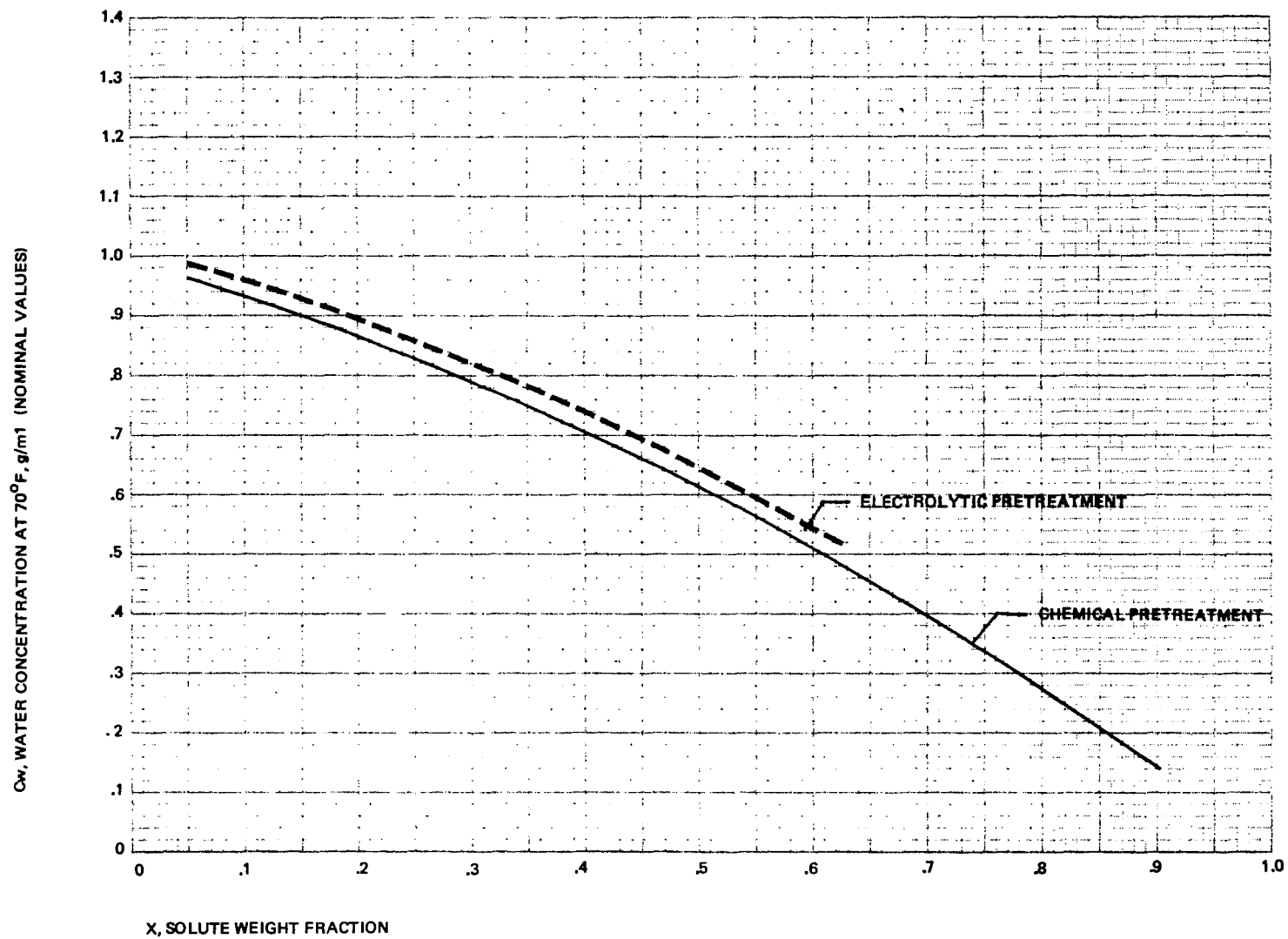


Figure 34. Water Concentration of Urine Concentrate

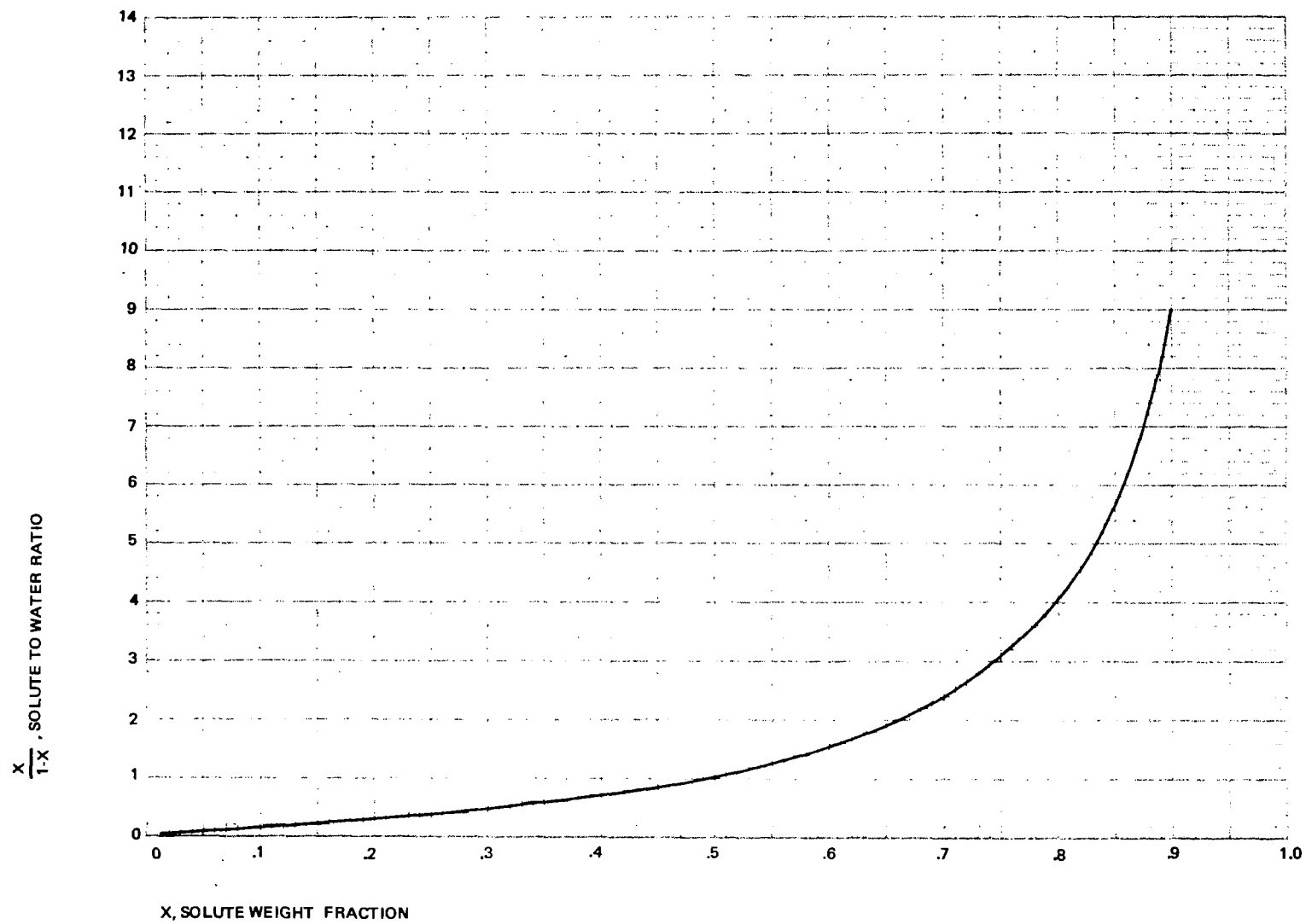


Figure 35. Solute to Water Ratio of Urine Concentrate

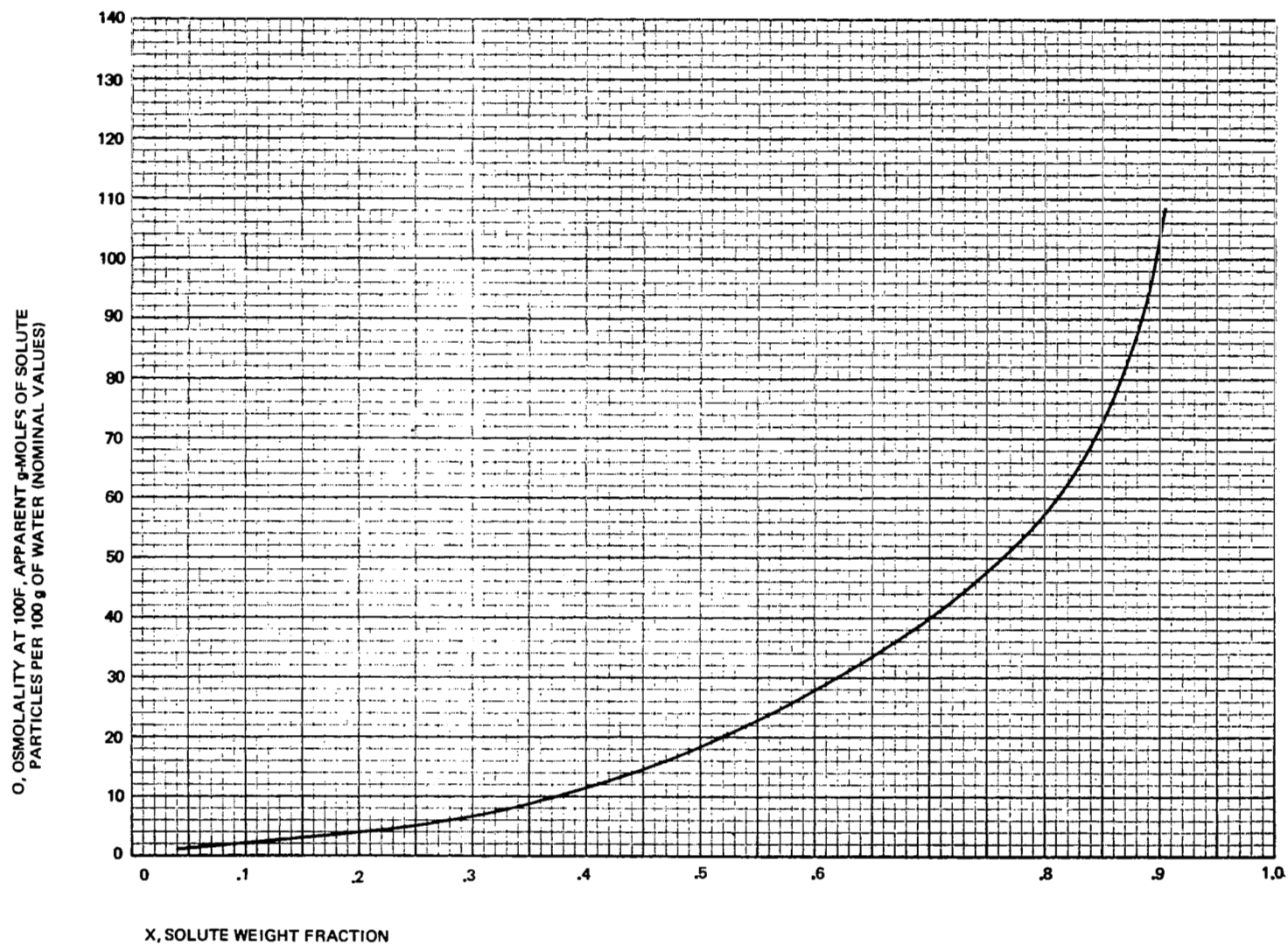


Figure 36. Osmolality of Urine Concentrate

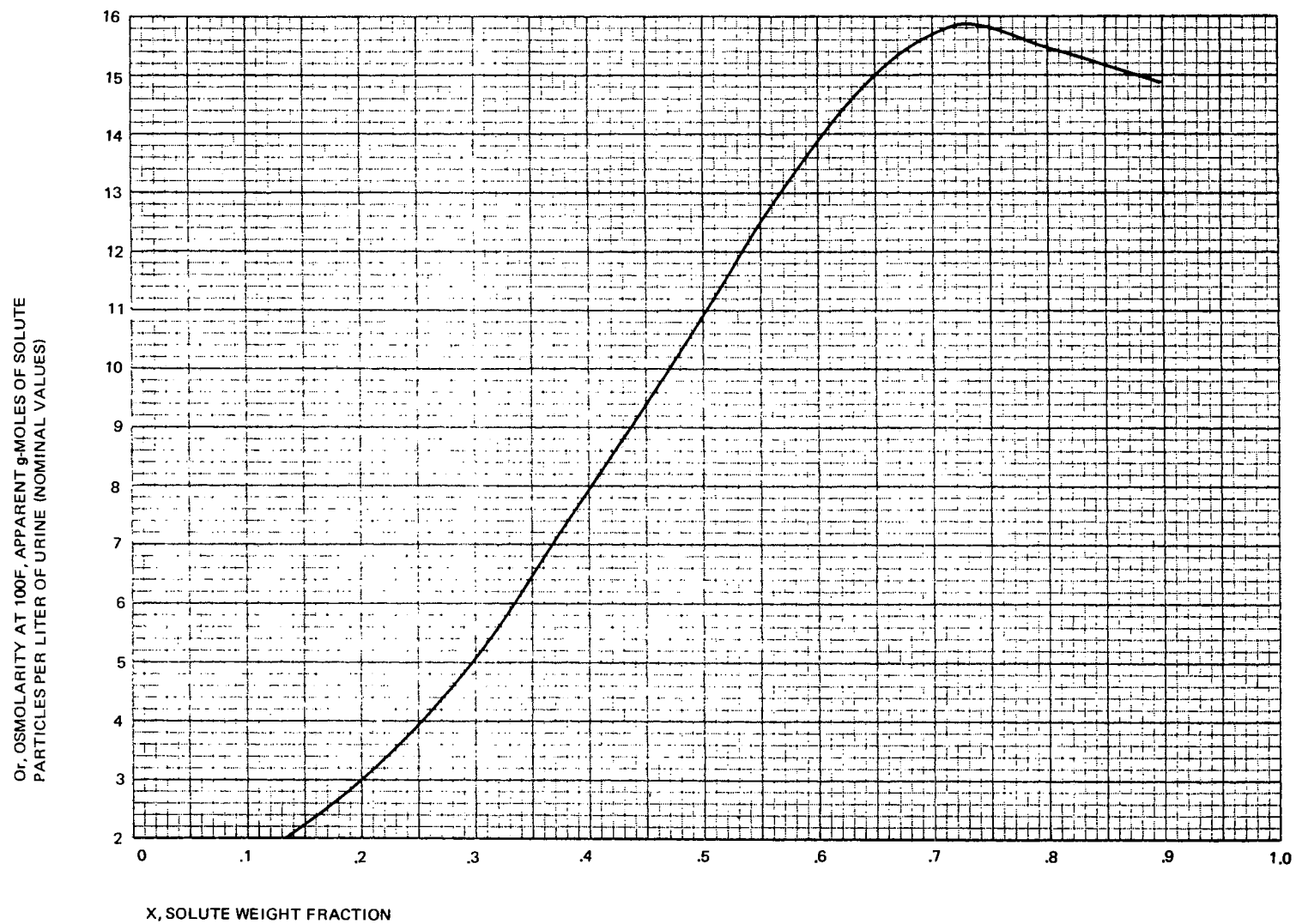


Figure 37. Osmolarity of Urine Concentrate

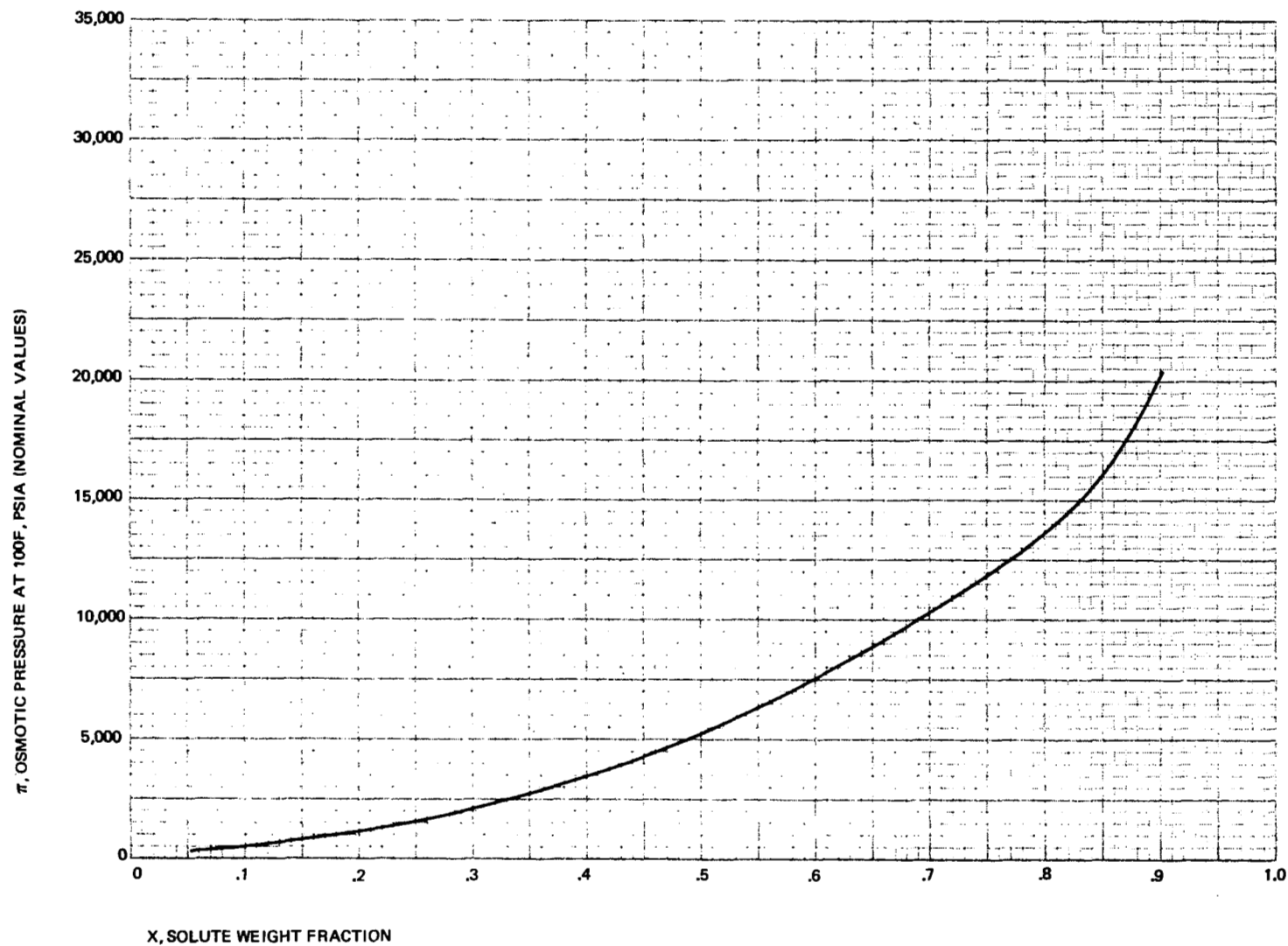


Figure 38. Osmotic Pressure of Urine Concentrate

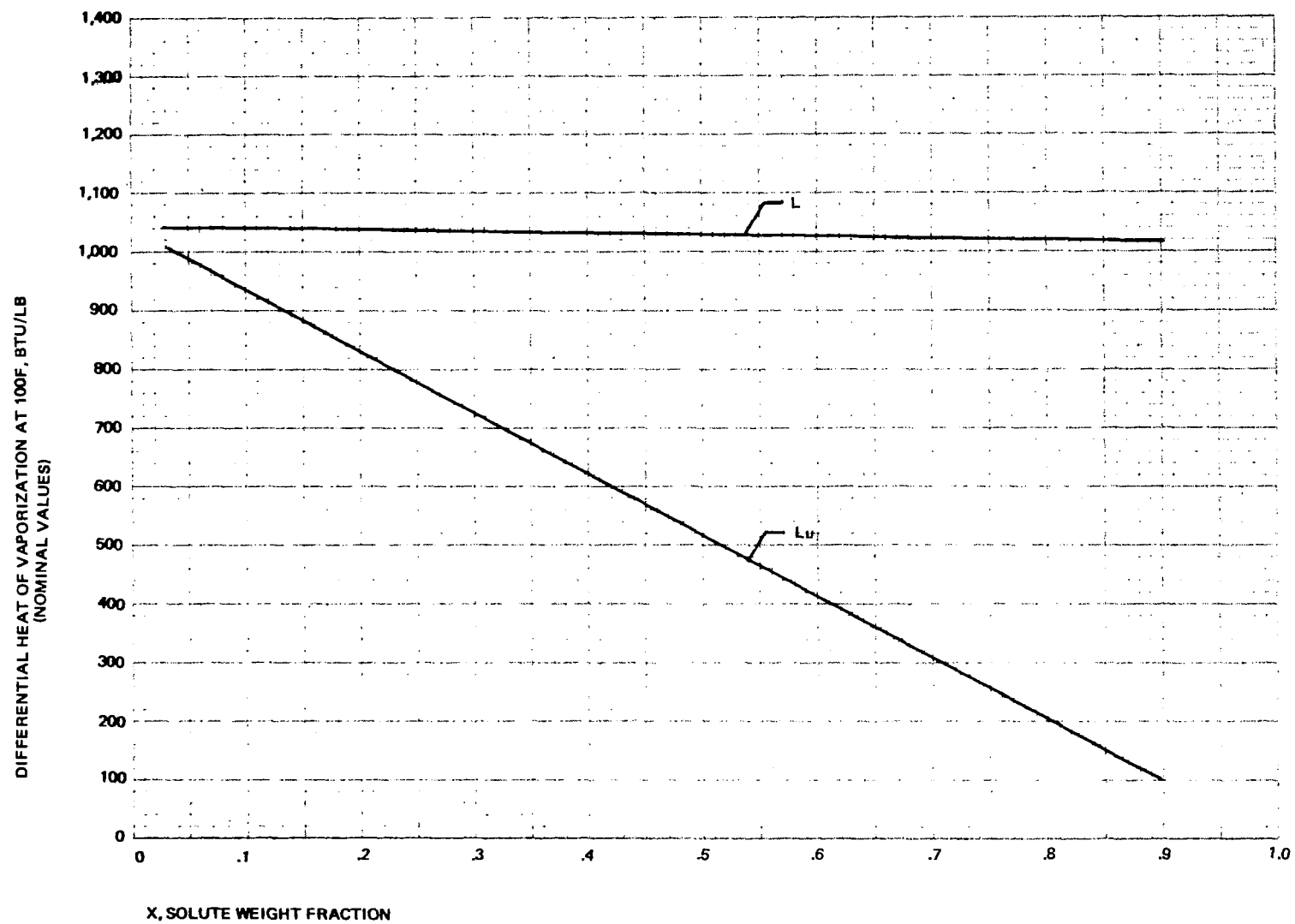


Figure 39. Differential Heat of Vaporization of Urine Concentrate

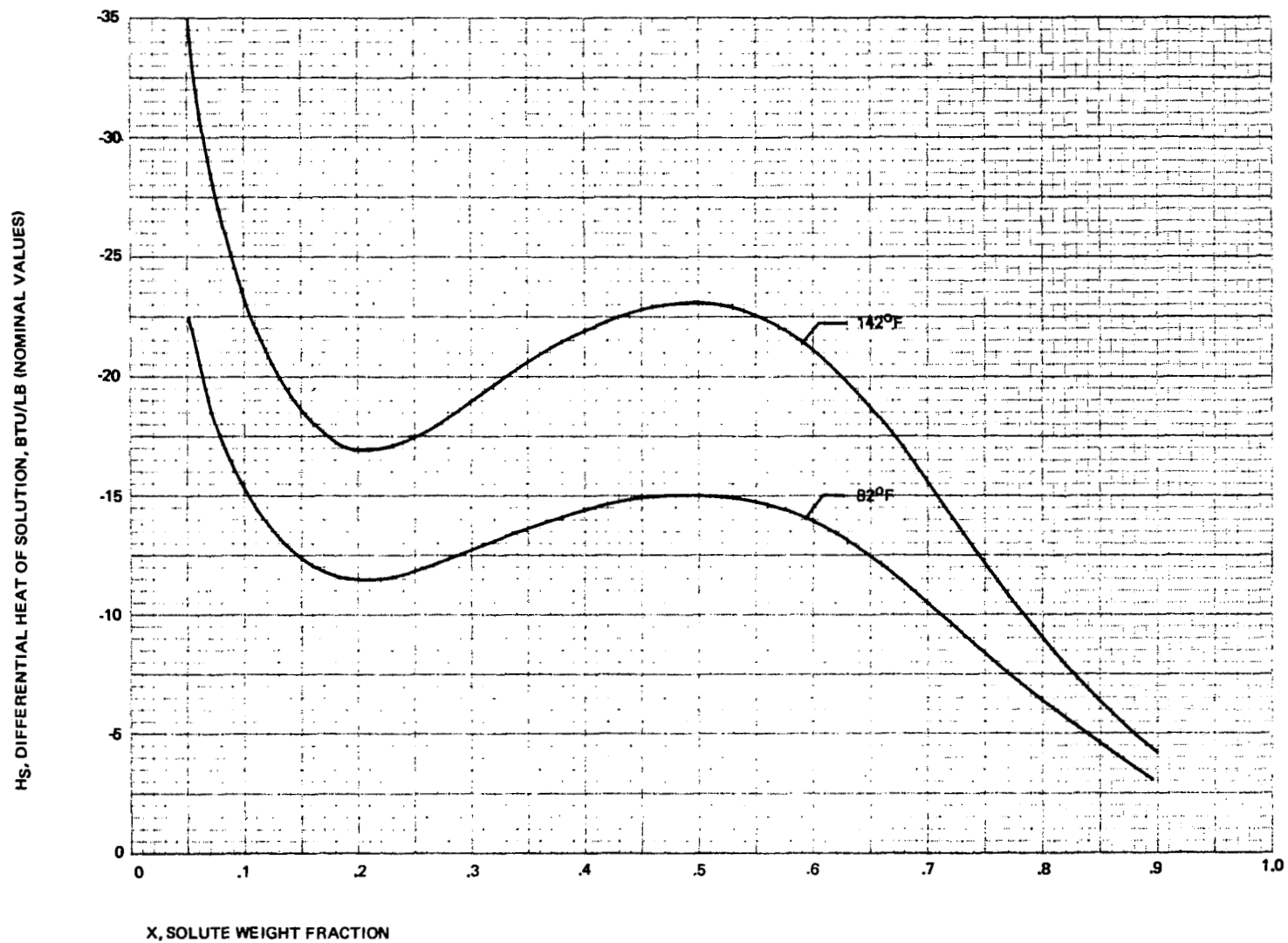


Figure 40. Differential Heat of Solution of Urine Concentrate

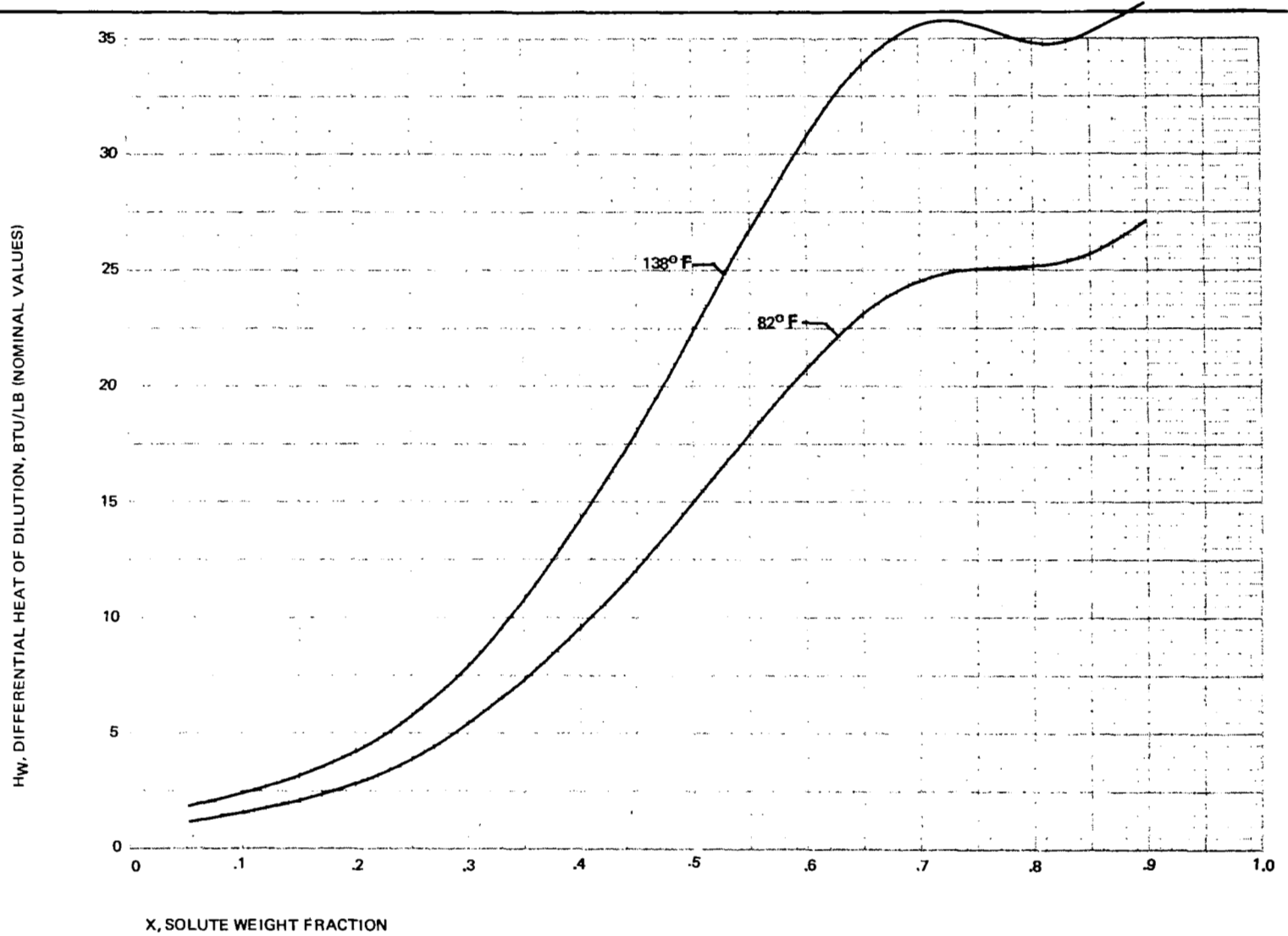


Figure 41. Differential Heat of Dilution of Urine Concentrate

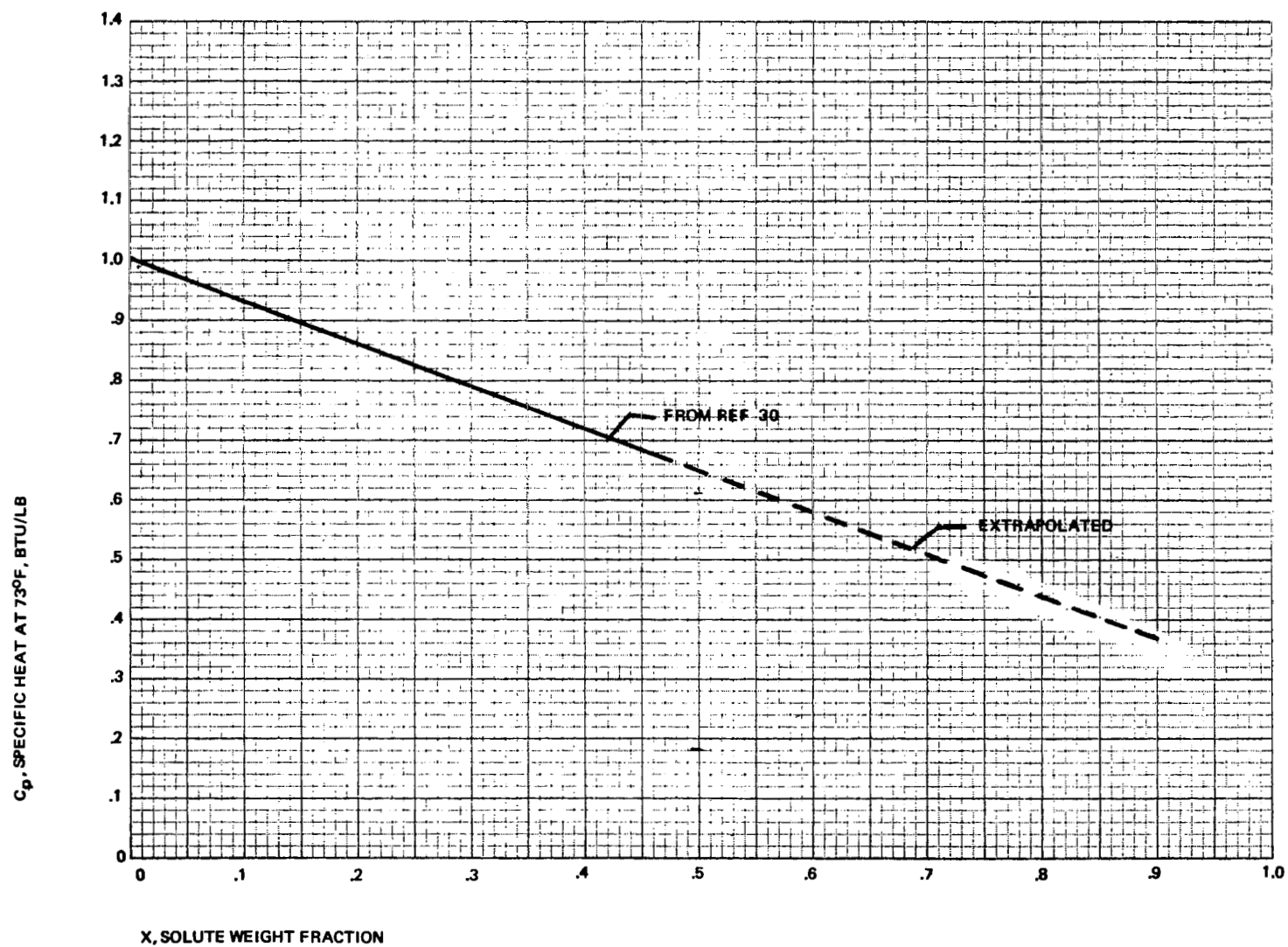


Figure 42. Specific Heat of Urine Concentrate

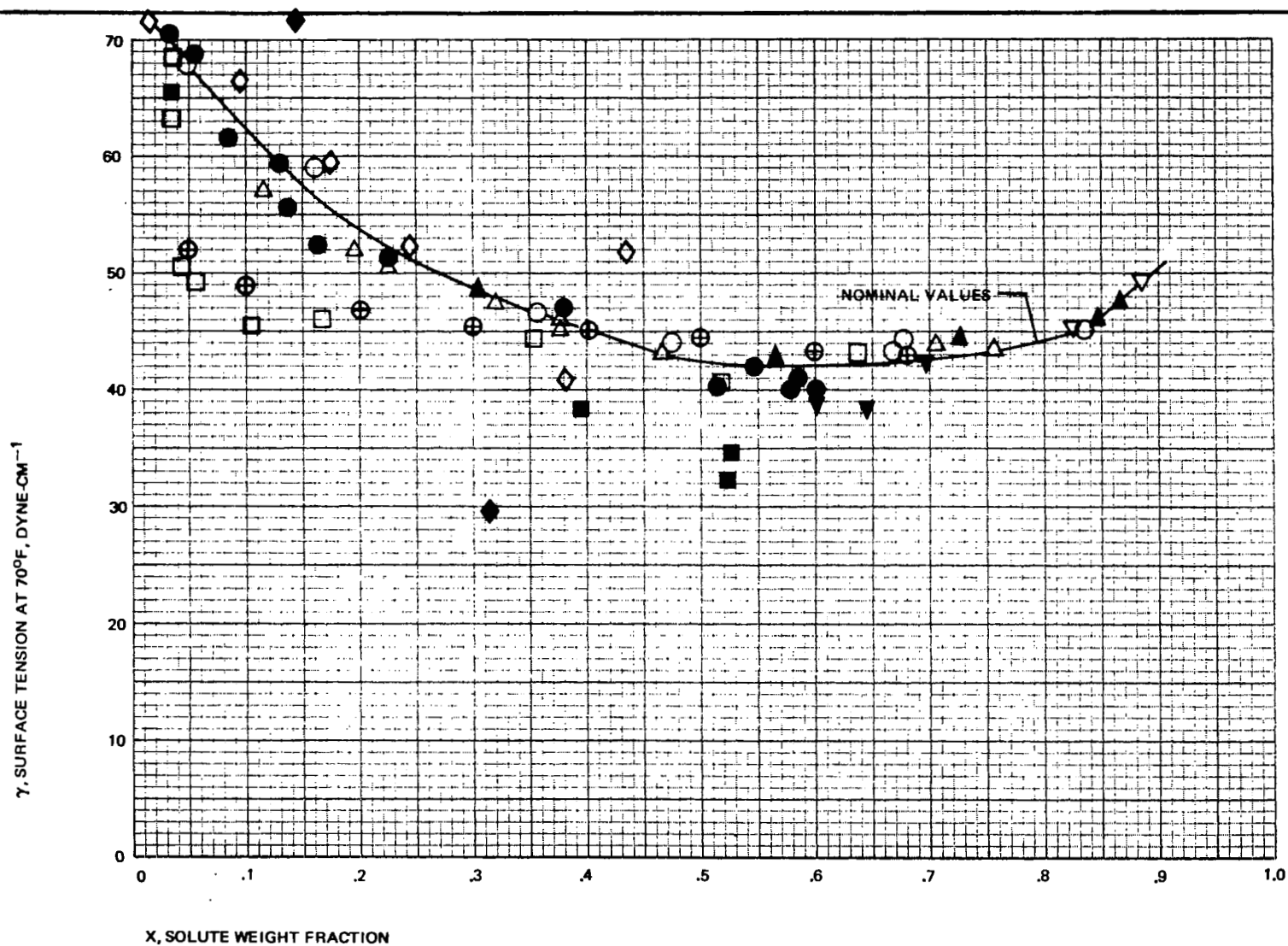


Figure 43. Surface Tension of Urine Concentrate

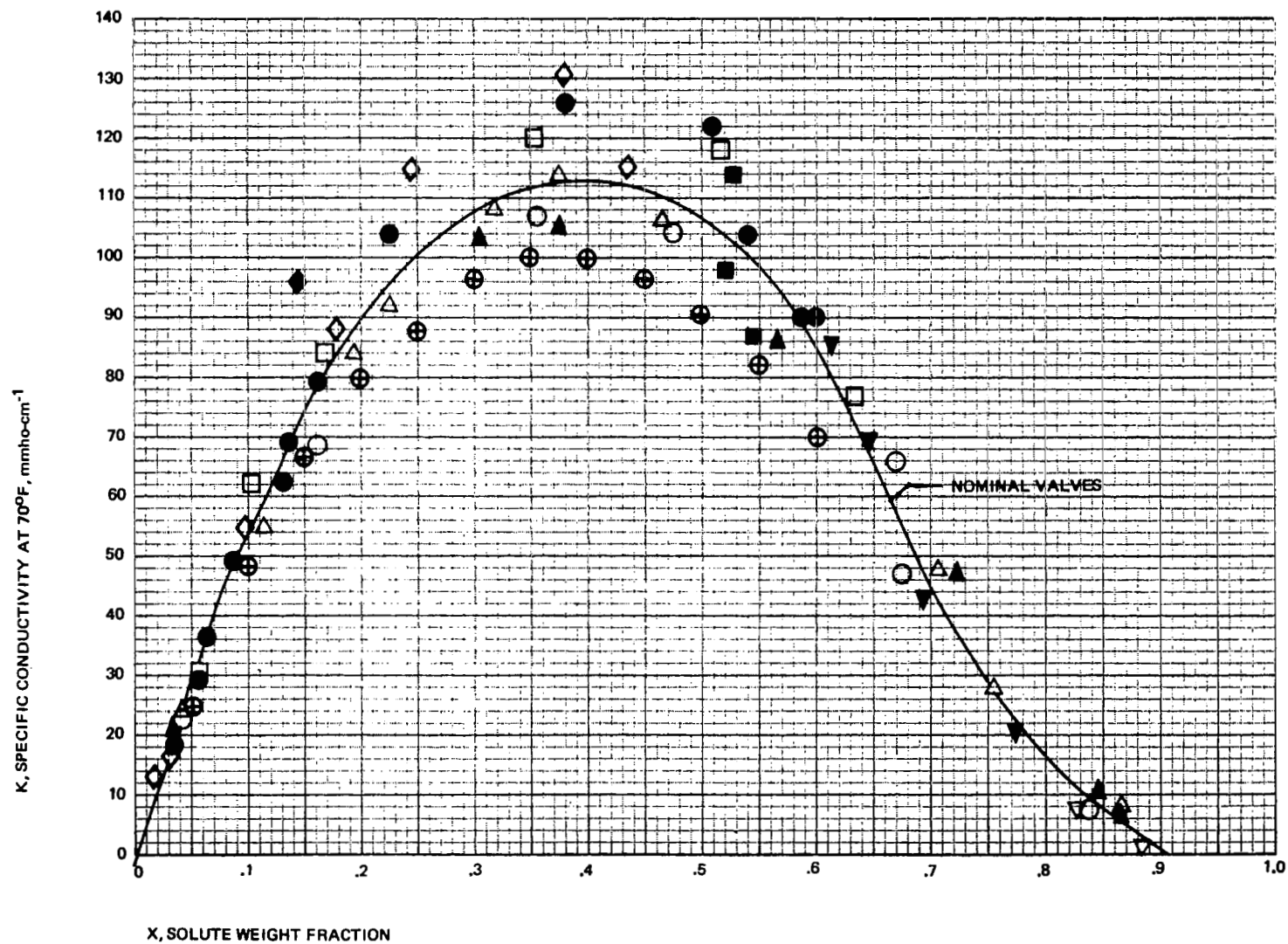


Figure 44. Specific Conductivity of Urine Concentrate

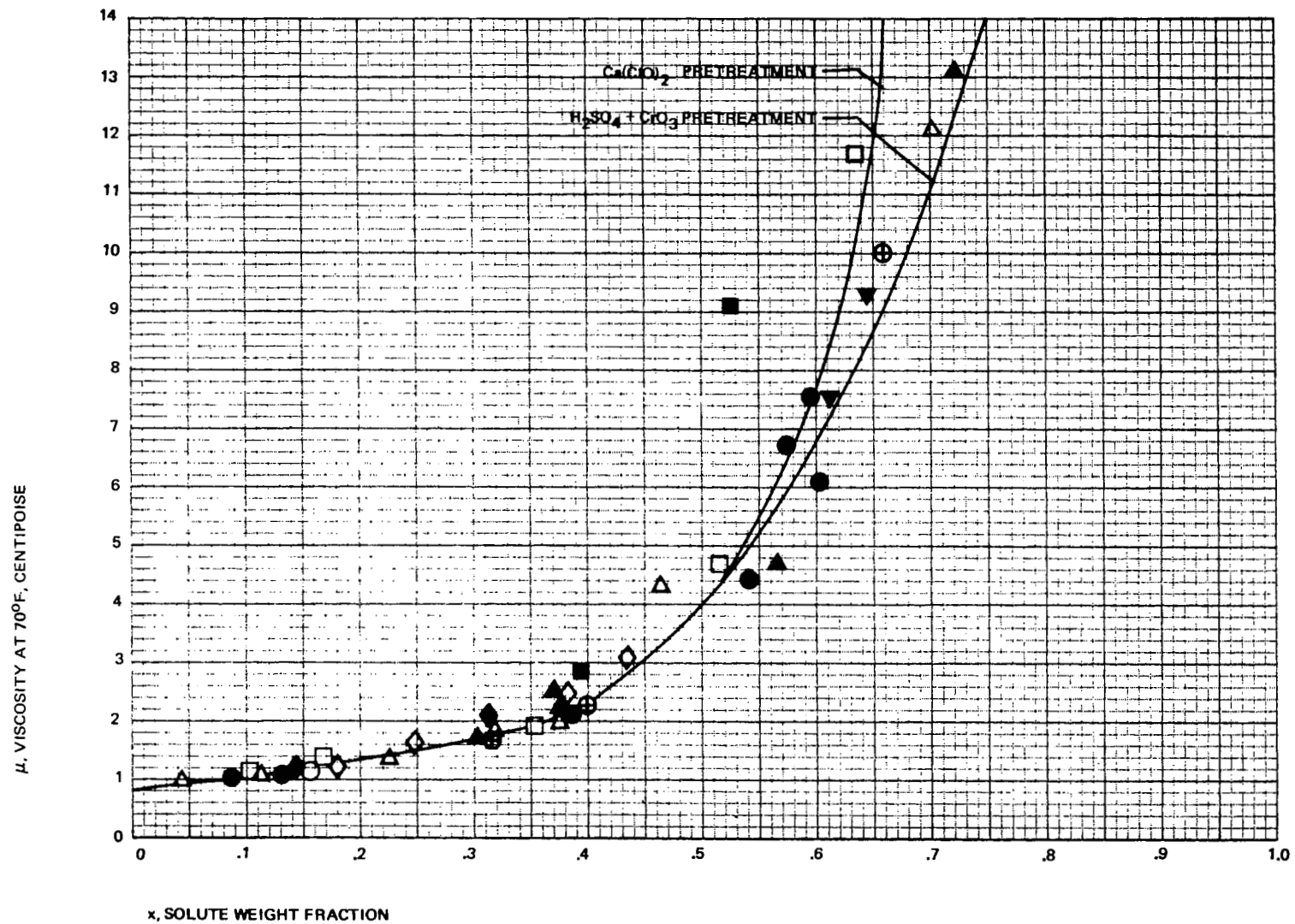


Figure 45. Viscosity of Urine Concentrate

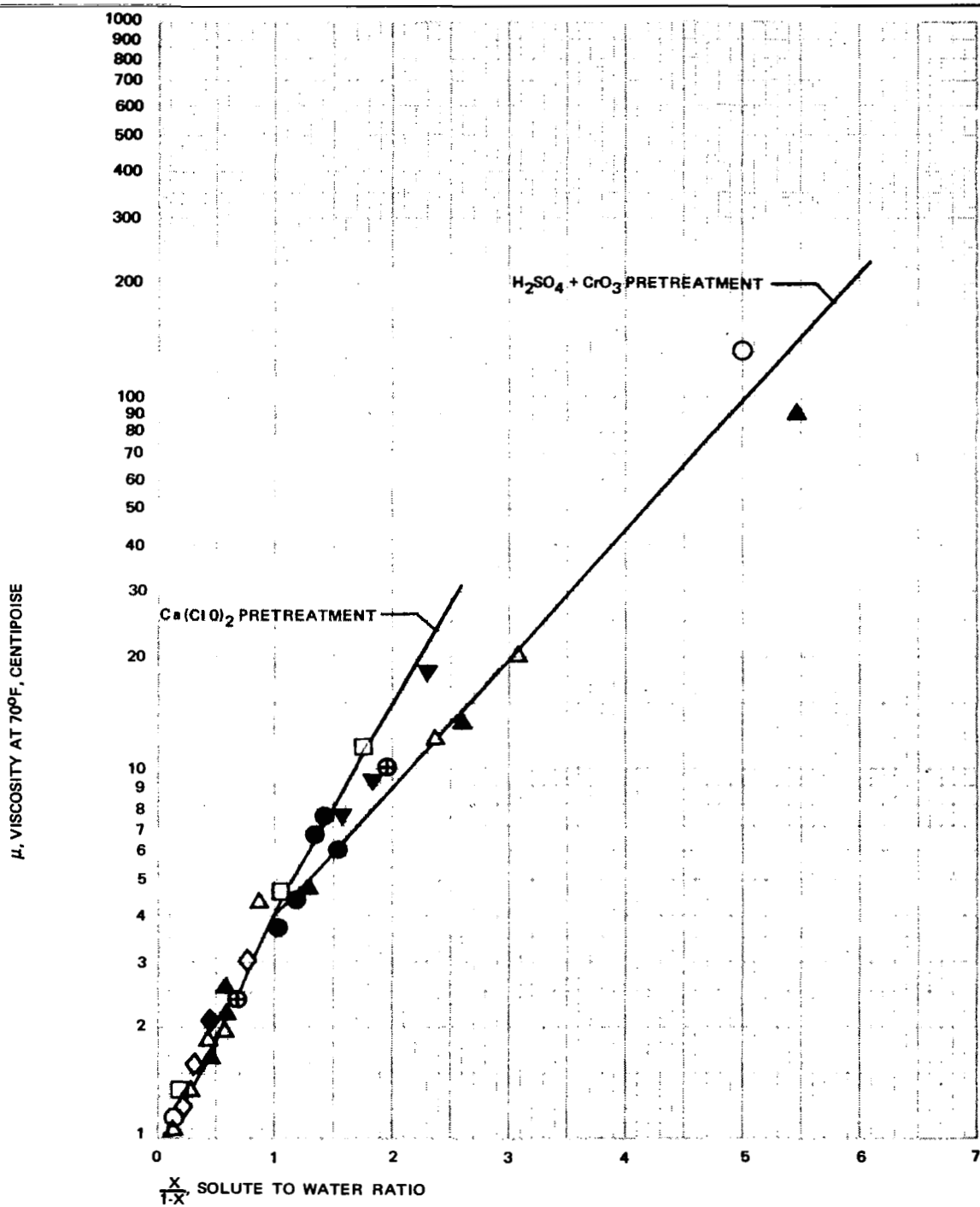


Figure 46. Viscosity as a Function of the Solute to Water Ratio

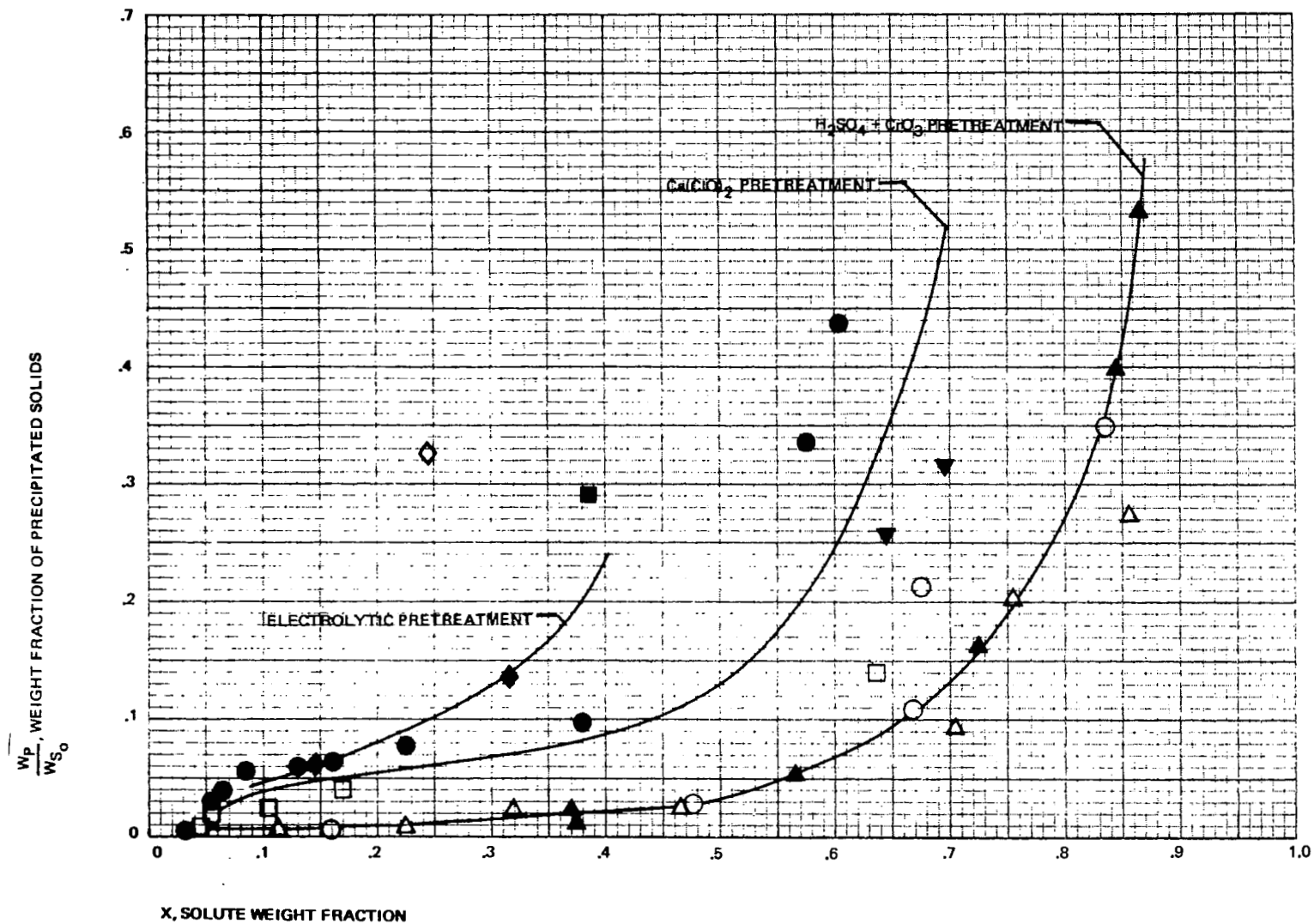


Figure 47. Weight Fraction of Solids Precipitated from Urine

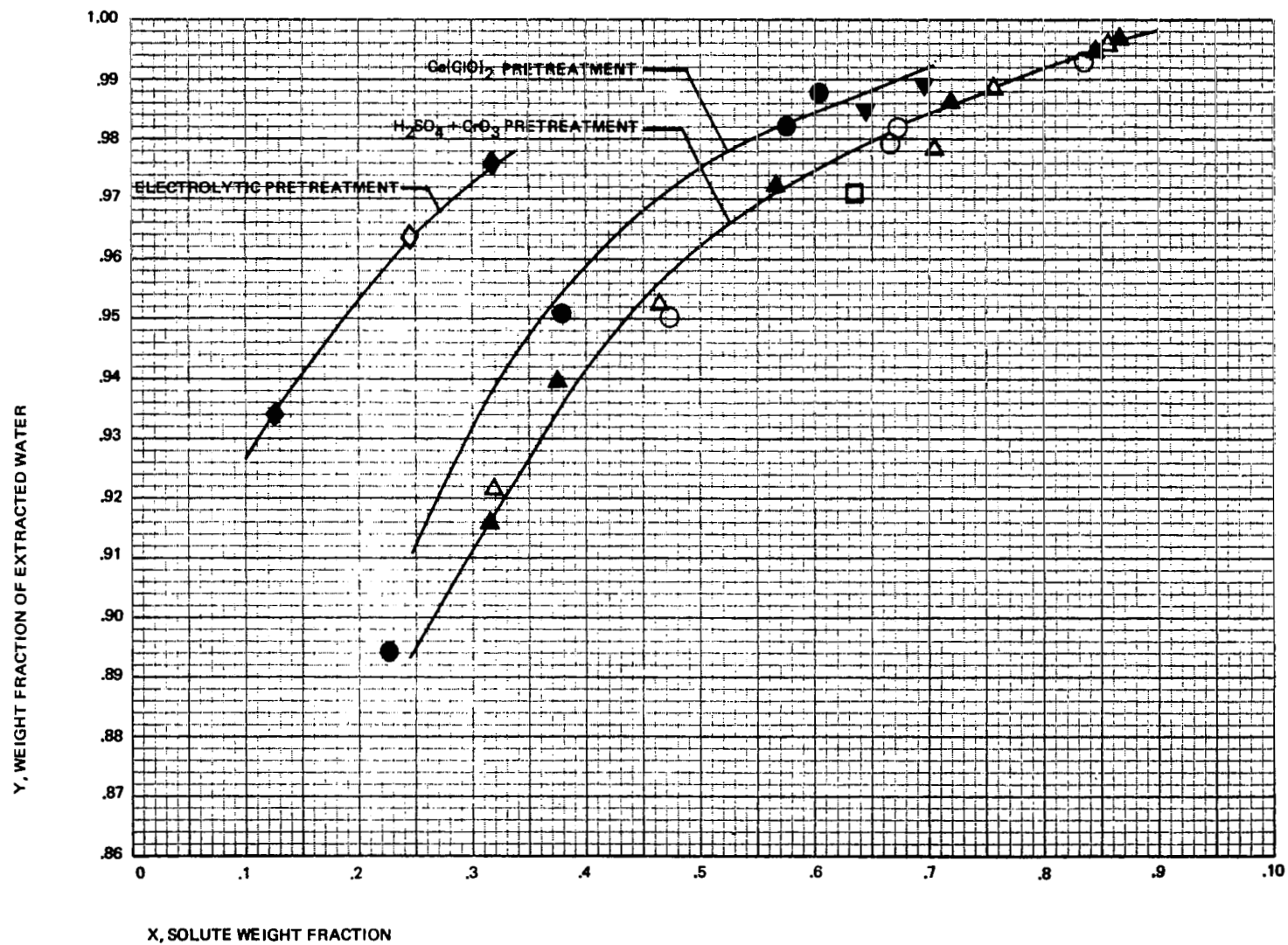


Figure 48. Weight Fraction of Water Extracted From Urine

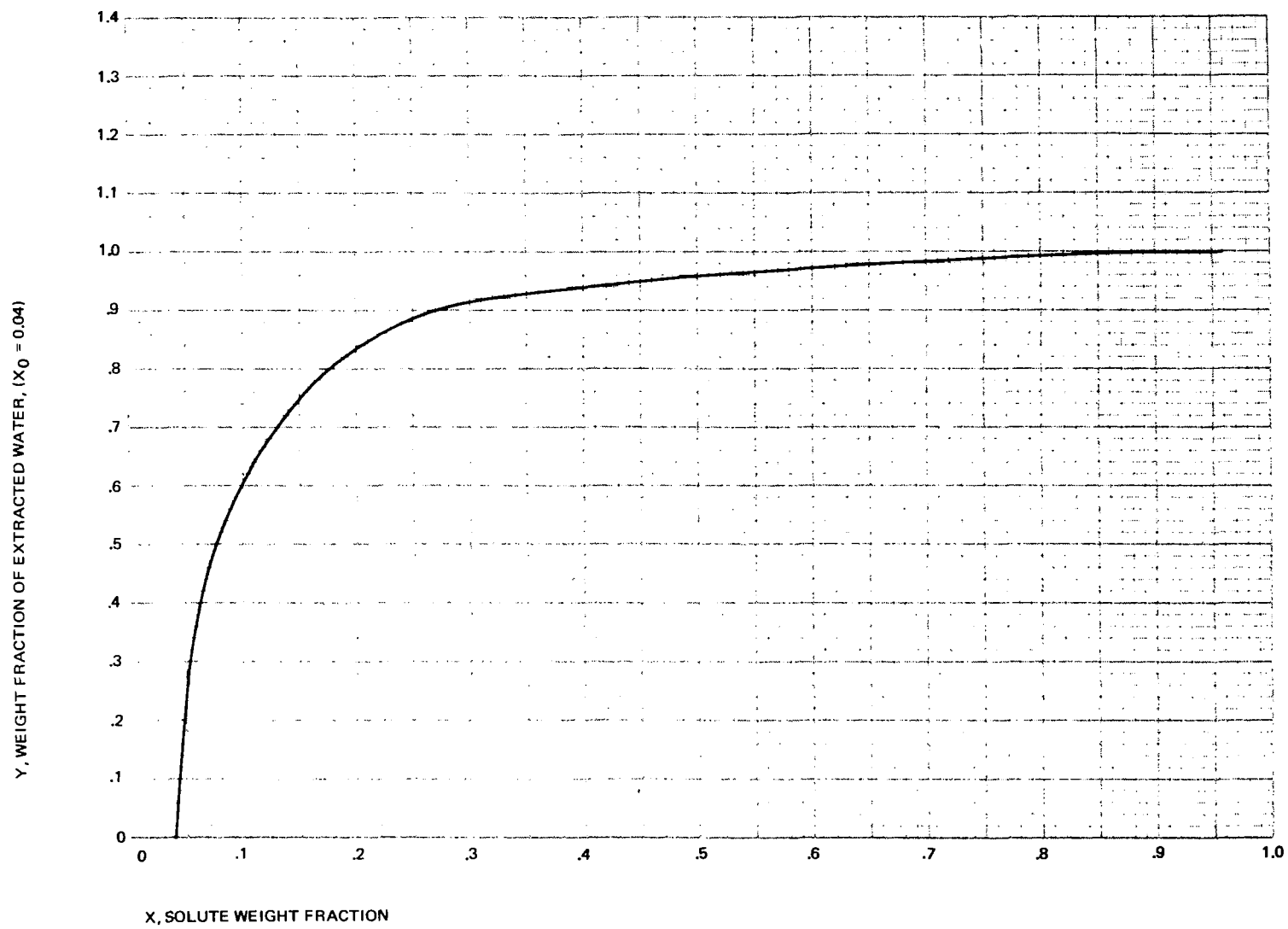


Figure 49. Weight Fraction of Extracted Water Versus Solute Weight Fraction

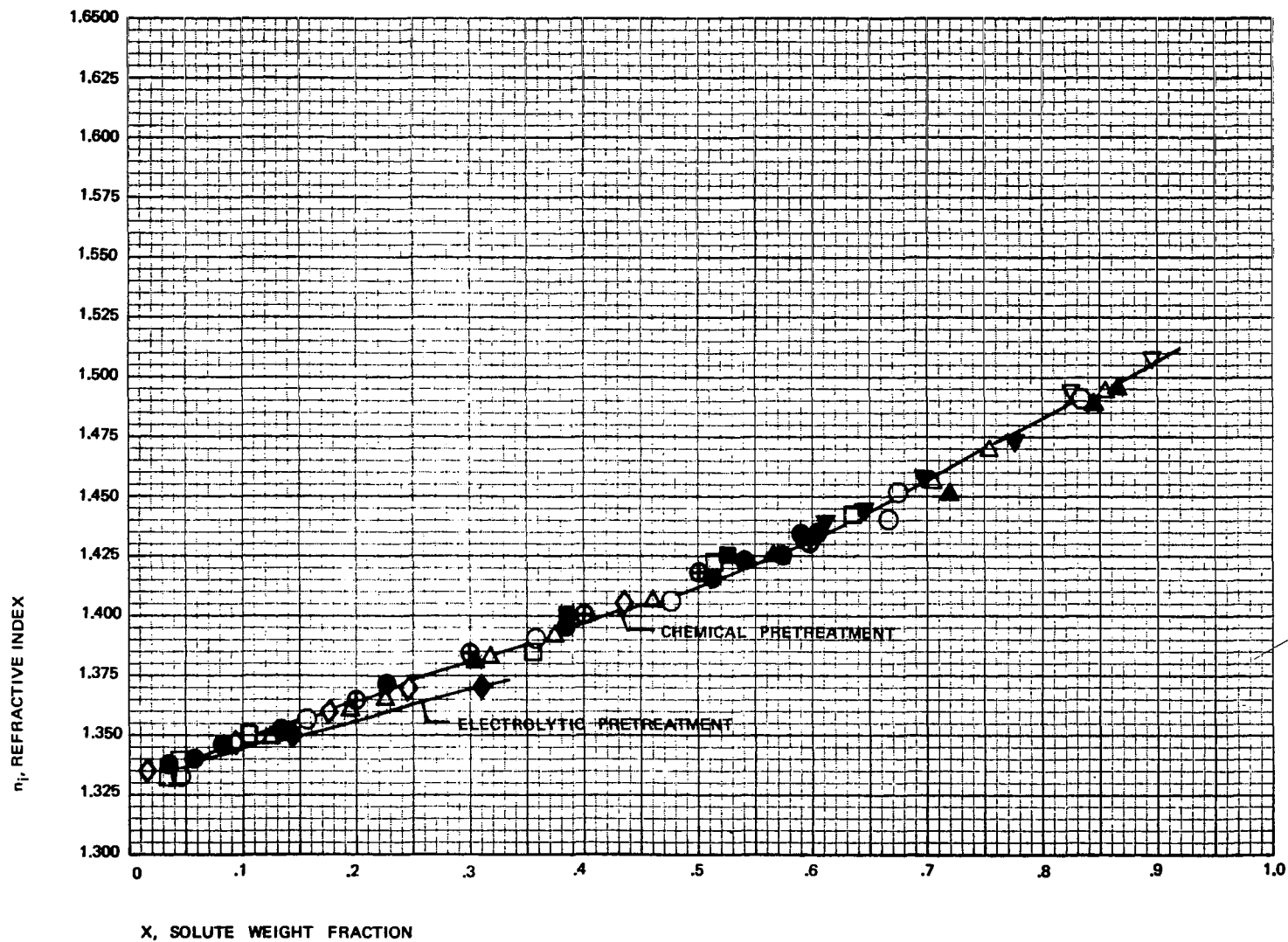


Figure 50. Refractive Index of Urine Concentrates

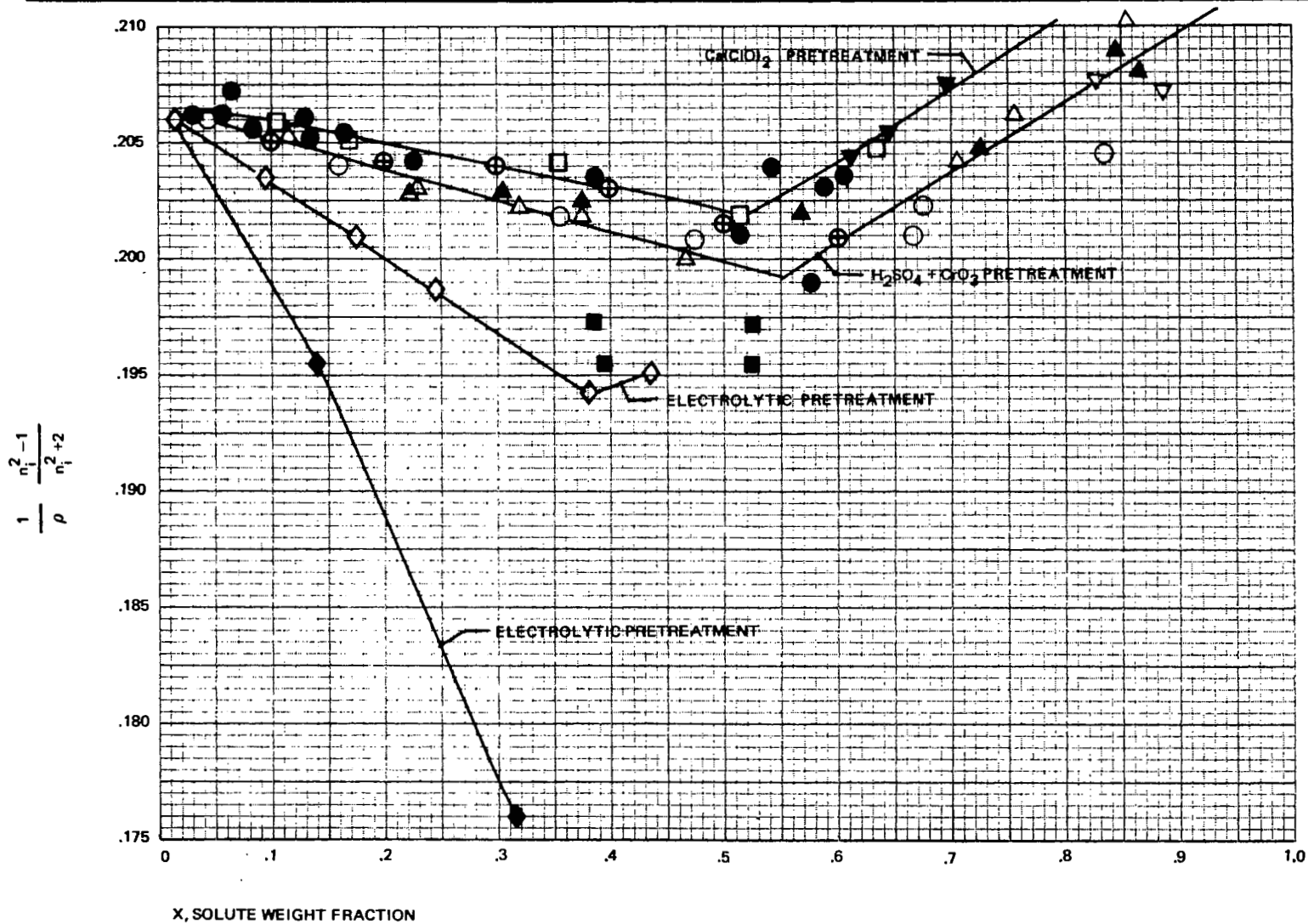


Figure 51. Linear Dependence of $\rho^{-1}(n_1^2 - 1)/(n_1^2 + 2)$ on Solute Weight Fraction

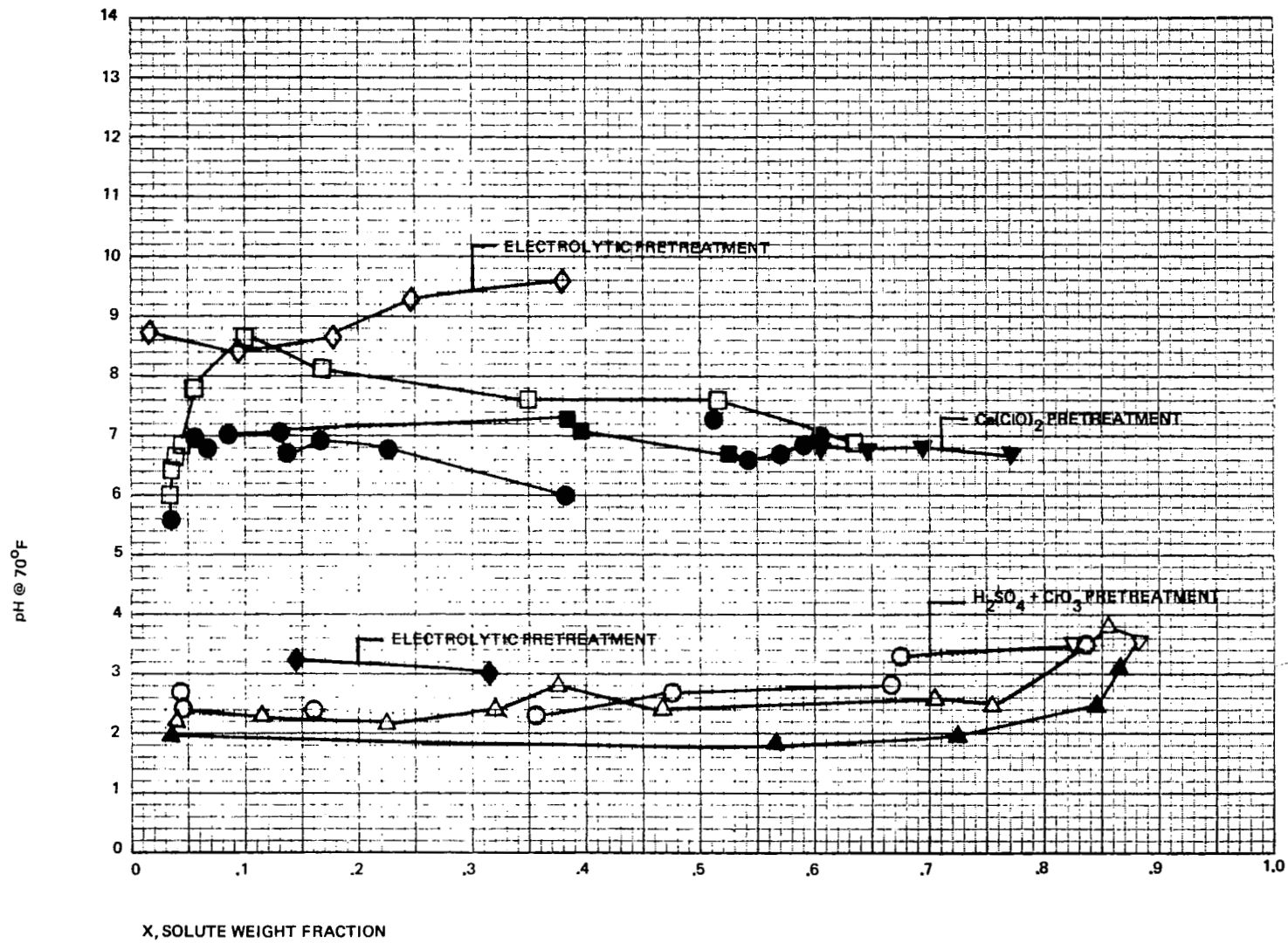


Figure 52. pH of Urine Concentrates